

DRUM - SHIRLEY BAY
INSTRUMENT SECTION
PLEASE RETURN

Sec 12

137B

INSTRUCTION MANUAL



MODEL 250-B
UNIVERSAL
IMPEDANCE BRIDGE

BROWN ELECTRO-MEASUREMENT CORPORATION
PORTLAND, OREGON

MODEL 250-C Impedance Bridge replaced by MODEL 250-C1

Accuracy improved on the Model 250-C1 to:

Resistance: $\pm$ (0.1% + 1 division on the LRC dial)

Capacitance: $\pm$ (0.25% + 1 division on the LRC dial)

Inductance: $\pm$ (0.9% + 1 division on the LRC dial)

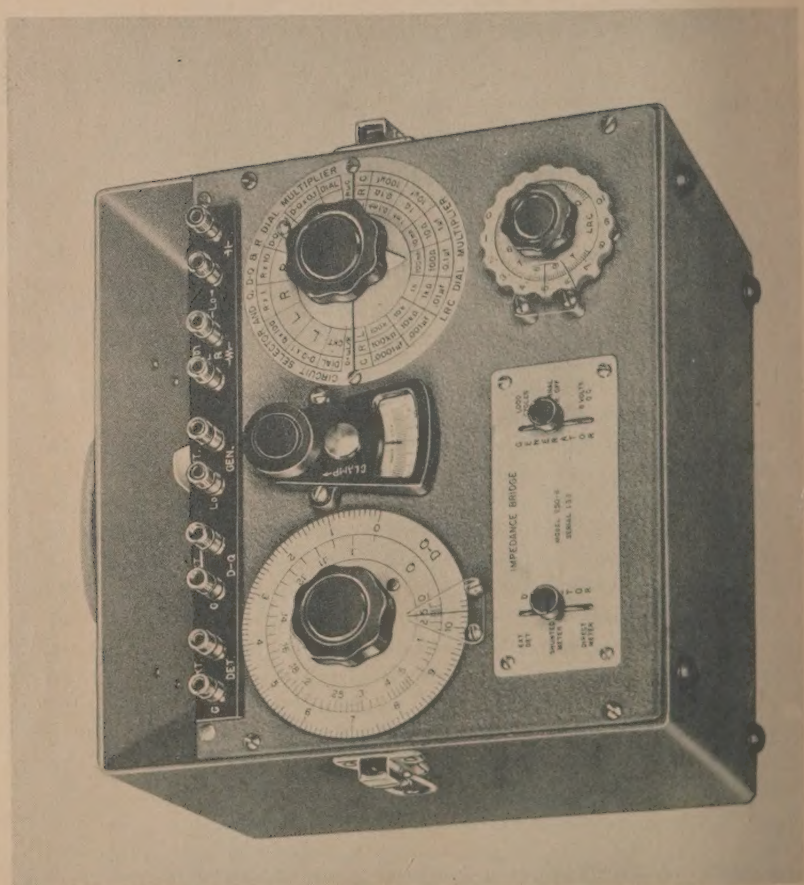
CONTENTS

	Paragraph	Page
CHAPTER 1. INTRODUCTION		
Section I. Description and Data		
General	1	1
Description of major components	2	1
Description of minor components	3	1
Symbols and abbreviations	4	2
Technical characteristics	5	2
CHAPTER 2. OPERATING INSTRUCTIONS		
Section I. General		
Installation of battery	6	5
Controls	7	5
Galvanometer	8	6
Binding posts	9	6
Section II. Resistance, Capacitance and Inductance Measurements.		
D-c resistance measurements	10	7
Accuracy of d-c resistance measurements	11	11
Making a-c resistance measurements at 1,000 cps	12	11
Accuracy of a-c resistance measurements	13	13
Capacitance measurements at 1,000 cps	14	13
Accuracy of capacitance measurements at 1,000 cps	15	17
Accuracy of dissipation factor measurements	16	17
Inductance measurements at 1,000 cps	17	17
Accuracy of inductance measurements at 1,000 cps	18	21
Accuracy of storage factor measurements	19	21
Section III. Miscellaneous bridge applications.		
General	20	21
Use of external d-c generator	21	22
Use of external a-c generator	22	23
Measurement of a-c resistance at frequencies other than 1 kc	23	25
Measurement of a-c resistance with reactance	24	26
Measurement of parallel capacitance and resistance of a capacitor	25	27
Measurement of three terminal capacitor	26	28
D-c polarizing voltage for electrolytic capacitors	27	28
Measurement of terminal capacitance of inductors	28	29
Measurement of series or parallel inductance and resistance of an inductor	29	29
Measurement of iron core inductors with d-c magnetizing current	30	30
Determining the resonant frequency of an inductor or tuned circuit	31	31
Measurement of D and Q at frequencies other than 1 kc	32	32
Use of LRC rheostat as a calibrated resistor	33	36

	Paragraph	Page
Section III. Miscellaneous bridge applications (continued).		
Use of bridge ratio arms as precision resistors	34	37
Use of bridge capacitor as secondary capacitance standard	35	37
Use of internal 1,000 cps hummer as external tone generator	36	38
Use of bridge galvanometer for measurement of small currents	37	38
CHAPTER 3. MAINTENANCE INSTRUCTIONS		
Section I. Lubrication and maintenance.		
Lubrication instructions	38	41
Preventive maintenance checklist	39	42
CHAPTER 4. THEORY OF BRIDGE OPERATION		
Section I. General		
General theory of operation	40	43
Description of the bridge circuits used	41	43
Discussion of residual impedances	42	48
CHAPTER 5. REPAIR AND CALIBRATION INSTRUCTIONS		
Section I. Trouble location and repair.		
Test, calibration, and repair equipment	43	53
Preliminary inspection and testing	44	53
Trouble-shooting chart	45	55
Trouble-shooting the Impedance Bridge	46	57
Preparatory procedures	47	57
Checking battery	48	57
Checking ratio arm A resistors	49	57
Checking ratio arm B resistors	50	58
Checking LRC decade-rheostat	51	58
Checking Q rheostat	52	59
Checking standard capacitor	53	59
External check of microphone hummer	54	60
Checking bridge galvanometer	55	60
Checking bridge chassis	56	61
More positive check of standard capacitor	57	63
Checking meter shunt resistors R-1 and R-2, and the series resistor R-3	58	63
Internal check of microphone hummer	59	63
Checking D and D-Q rheostats	60	64
Repairing the Impedance Bridge	61	65
Section II. Calibration		
Calibration of ratio arm A resistors	62	65
Calibration of ratio arm B resistors	63	65
Calibration of LRC decade-rheostat	64	66
Calibration of D and Q rheostats	65	66
Calibration of standard capacitor	66	67
Section III. Final testing and refinishing.		
Testing the Impedance Bridge after repair or adjustment...	67	67
Refinishing case of Impedance Bridge	68	68

LIST OF ILLUSTRATIONS

Fig. No.	Title	Page
1	Identification of panel controls	4
2	Controls set for measurement of d-c resistance (0.001 ohm to 1 megohm)	8
3	Controls set for measurement of d-c resistance (1 megohm to 11 megohms)	10
4	Controls set for measurement of a-c resistance	12
5	Controls set for measurement of capacitors with dissipation factors from 0.001 to 0.105	14
6	Controls set for measurement of capacitors with dissipation factors from 0.1 to 1.05	16
7	Controls set for measurement of inductors with storage factors from 0.02 to 10.5	18
8	Controls set for measurement of inductors with storage factors from 10 to 1000	20
9	Resistance bridge circuit	44
10	Capacitance bridge circuit	44
11	Maxwell inductance bridge circuit	44
12	Hay inductance bridge circuit	44
13	Resistance bridge circuit with major residuals	46
14	Capacitance bridge circuit with major residuals	46
15	Maxwell inductance bridge circuit with major residuals	46
16	Hay inductance bridge circuit with major residuals	46
17	Residual impedances	50
18	Bridge chassis	62
19	Schematic diagram of the Impedance Bridge	69
20	Practical wiring diagram of the Impedance Bridge	70



Frontispiece. Model 250-B Impedance bridge

CHAPTER 1

INTRODUCTION

Section 1. DESCRIPTION AND DATA

1. General

This Impedance Bridge is a portable, self-contained instrument designed for rapid and accurate measurement of resistance, capacitance, inductance, dissipation factors of capacitors, and the storage factors of inductors.

2. Description of Major Components (fig. 1)

a. GENERAL. This impedance bridge is a four-arm bridge of standard design (par. 40) and is housed in an aluminum case which has a detachable lid and a removable front panel. All controls are located and clearly identified on the front panel. A carrying handle is located on the side of the case.

b. PANEL. Located on the front panel are the controls used to obtain readings. They are: a calibrated D-Q dial, an engraved CIRCUIT SELECTOR switch and LRC DIAL MULTIPLIER switch, and an LRC dial. Binding posts (plainly marked) are provided for attachment of an external generator, a detector, an external rheostat for extending the D-Q measurement ranges, and for attaching the inductors, capacitors, and resistors to be measured. The galvanometer, located at the approximate center of the panel, is a 7.5-0-7.5 microampere meter with an internal resistance of 1,000 ohms. Two switches (GENERATOR and DETECTOR) with self explanatory labels, complete the controls illustrated on figure 1.

c. CHASSIS. The aluminum front panel is used to support all the bridge components. The internal parts of the instrument are mounted on the rear of the panel as shown in figure 18, and are easily reached for making repairs and adjustments.

d. BATTERY COMPARTMENT. The batteries used to power the impedance bridge are enclosed in a fibre cartridge located in the compartment at the top of the bridge (fig. 1).

3. Description of Minor Components

a. HEADSET. One headset is used with (but not furnished with) the Impedance Bridge. The headset used should have a threshold voltage of about 1 millivolt at 1 kc. It is used to obtain aural indication of balance when making a-c measurements.

b. BATTERY. Four flashlight cells (size "D") are used with the bridge. A removable fibre cartridge holds this 6-volt battery so that the cells are connected in series. Spring contacts make the necessary bridge connections to the ends of the battery.

c. TEST LEADS. Two test leads are provided for making connections to the bridge.

4. Symbols and Abbreviations

Before using the instrument, carefully study the following symbols and abbreviations used in this manual. A thorough understanding of them is necessary in order to make full use of the bridge. Formulas used in this manual contain the following symbols:

R = Resistance	$\tan$ = tangent
R_s = Series resistance	$\sin$ = sine
R_p = Parallel resistance	Q = Storage factor
C = Capacitance	X = Reactance
C_s = Series capacitance	Z = Impedance
C_p = Parallel capacitance	f = frequency
L = Inductance	$\omega = 2\pi f$
L_s = Series Inductance	$\pi = 3.1416$
L_p = Parallel inductance	θ = Theta (phase angle)
p/f = power factor	$k = 1 \text{ kilohm} = 1,000 \text{ ohms}$
$\cot$ = cotangent	D = Dissipation factor

5. Technical Characteristics

a. RANGE. The ranges of the bridge circuits are as follows:

- (1) Capacitance 1 micromicrofarad to 1100 microfarads.
- (2) Resistance 1 milliohm to 11 megohms.
- (3) Inductance 1 microhenry to 1100 henrys.
- (4) Dissipation factor R/X or D 0.001 to 1.0.
- (5) Storage factor X/R or Q 0.02 to 1,000.

b. ACCURACY. The accuracy of the bridge under normal conditions of operation, temperature, and humidity are given for the five intermediate ranges in the table below. On the two extreme ranges, i.e., the highest and the lowest, these limits of error may be exceeded.

Measurement	Limits of error
Resistance	$\pm(0.15\% + 1 \text{ division on LRC dial})$
Capacitance	$\pm(0.5\% + 1 \text{ division on LRC dial})$
Inductance	$\pm(1.0\% + 1 \text{ division on LRC dial})$
Dissipation factor (D)	$\pm(7\% + 0.0025)^*$
Storage factor (Q)	Expressed in terms of its reciprocal D, $\pm(7\% + 0.0025)^*$

**Note.* These errors may be exceeded under abnormal conditions of operation.

c. PRECISION. The main LRC dial has 1,100 divisions spaced approximately 1 millimeter apart over nearly 4 feet of scale length. The internal galvanometer permits δ - ϵ resistance balances to be made to approximately 0.1% or better on the five intermediate ranges.

d. FREQUENCY RESPONSE. The readings of the main LRC dial are essentially independent of frequency from 60 cycles to 10 kilocycles on the intermediate ranges. Storage factor (Q) readings on the Q scale must be divided by the generator frequency in kilocycles. The storage factor (Q) and dissipation factor (D) readings on the D-Q scale must be multiplied by the generator frequency in kilocycles.

e. INTERNAL GENERATOR. A 1,000 cps microphone hummer (fig. 18), accurate to within $\pm 5\%$ is used as the internal bridge generator. The generator is coupled to the bridge by a carefully isolated and shielded coil to minimize the effects of stray capacitance to ground and to eliminate extraneous voltages across the bridge arms. The entire generator is enclosed in a special shield which provides both electromagnetic and electrostatic shielding and reduces errors caused by the effects of stray fields upon the components being measured.

f. PACKAGING. Domestic packaging data:

No. of packages	Dimensions (in.)			Vol. (cu. ft.)	Weight (lb)
	Height	Width	Length		
1	11½	12½	13½	1.13	20

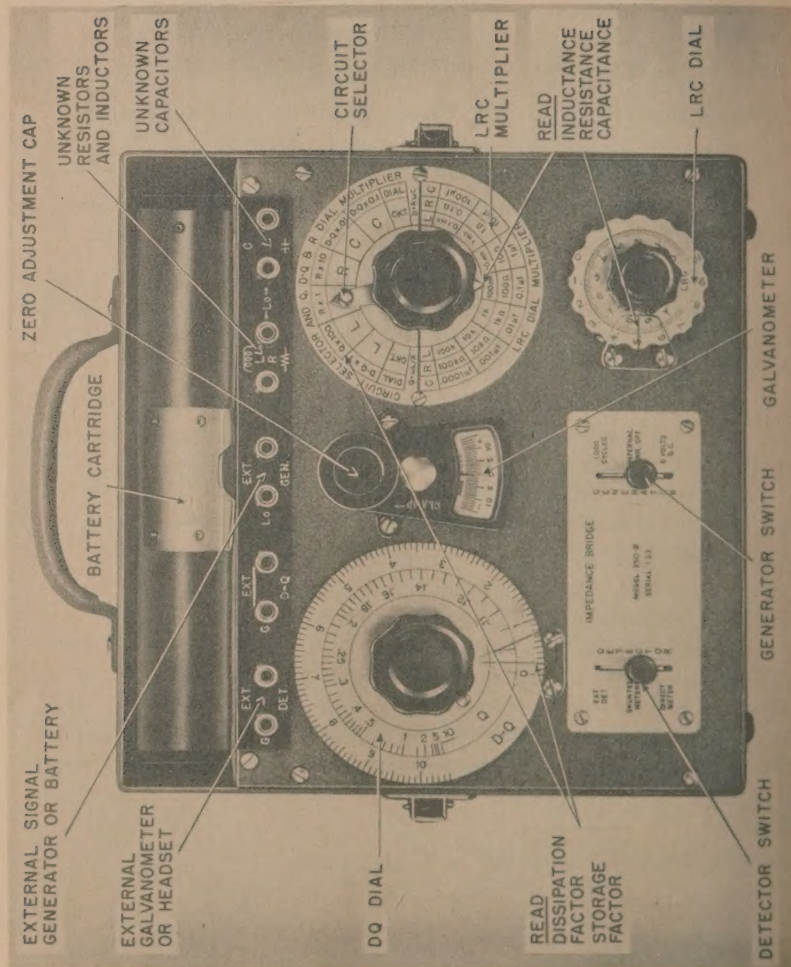


Figure 1. Identification of panel controls.

CHAPTER 2

OPERATING INSTRUCTIONS

Section 1. GENERAL

6. Installation of Battery

a. Unsnap and remove fibre cartridge from compartment at top of bridge (fig. 1).

b. Remove test leads packed in cartridge.

c. Insert four, new, size "D" flashlight cells in series with the positive terminals pointing toward the end of the cartridge marked with a red dot.

d. Insert and snap down battery cartridge.

7. Controls

The bridge controls are as shown and identified in figure 1. Their functions are as follows:

a. **CIRCUIT SELECTOR.** Through the use of the CIRCUIT SELECTOR the proper bridge circuit for a particular measurement is selected by moving the lever pointer to the type of measurement indicated on the engraved CIRCUIT SELECTOR plate.

b. **LRC DIAL MULTIPLIER.** The LRC DIAL MULTIPLIER switch, mounted coaxially with the CIRCUIT SELECTOR switch, is operated by the black bakelite knob. When a balance has been reached, read the multiplying factor indicated by the white pointer on the LRC DIAL MULTIPLIER scale.

c. **LRC DIAL.** The bridge balance is reached by the manipulation of this dial. To read values of inductance (L), resistance (R), or capacitance (C) from this dial, see illustrations in paragraphs 10, 12, 14, and 17. Multiply the readings by the factor indicated on the LRC DIAL MULTIPLIER to obtain the value of the component being measured.

d. **D-Q and Q DIAL.** The storage factor (Q) of inductors from 0.02 to 10.5, and the dissipation factor (D) of capacitors from 0.001 to 1.05 are read on the outer ring marked D-Q. The red Q scale is used for reading the storage factors of inductors from 10 to 1,000.

e. **GENERATOR AND DETECTOR.** (1) *General.* The GENERATOR and DETECTOR switches are located in the lower left-hand corner of the panel (fig. 1).

(2) *D-c resistance measurements.* Set the GENERATOR switch to 6 VOLTS D.C. to connect the internal battery to the bridge. Set the

DETECTOR switch to SHUNTED METER to connect the galvanometer for obtaining the initial balance. When the galvanometer pointer is within one division of zero, set the DETECTOR switch to DIRECT METER for obtaining the final balance adjustment.

(3) *A-c resistance measurements.* Set GENERATOR switch to 1,000 CYCLES to connect the internal hummer. Set DETECTOR switch to EXT. DET. to connect EXT. DET. binding posts to the circuit for the operation of headphones or other suitable a-c null detector. To use an external generator, either a-c or d-c, set the GENERATOR switch to INTERNAL PWR. OFF. This connects the EXT. GEN. binding posts to the bridge. See paragraph 22 for further instructions on the use of a-c external generators.

8. Galvanometer

7.5-0-7.5 microampere galvanometer (internal resistance of 1,000 ohms) is located in the center of the panel (fig. 1). To place in operation pull the CLAMP button downward to release the galvanometer movement. Adjust the pointer to zero by rotating the round bakelite cap at the top of the meter. (If this cap does not turn easily, loosen the locking screw on the right-hand side of the cap. After the zero adjustment has been made, this screw should be retightened). When measurements are completed, push the CLAMP back to protect the meter movement.

WARNING: At the completion of the measurement return the GENERATOR switch to INTERNAL PWR. OFF and the DETECTOR switch to SHUNTED METER before disconnection of the component under test to avoid damage to the galvanometer.

9. Binding Posts

All binding posts are screw-type, jack-top connectors mounted on a common terminal board.

a. *EXTERNAL DETECTOR BINDING POSTS.* These two binding posts are labeled EXT. DET. on the common terminal board. The left post is grounded to the metal case, and is marked G. The EXT. DET. binding posts are used to connect a headset or other null detector to the bridge for determination of the null point when balancing the bridge.

b. *EXTERNAL D-Q BINDING POSTS.* These two binding posts are labeled EXT. D-Q on the common terminal board. The left post is grounded to the case, and is marked G. These binding posts, normally shorted with a bus bar during bridge operation, allow the extension of the bridge D-Q range. The D-Q range is extended by replacing the shorting bar with a decade box or calibrated rheostat. This places the extra resistance in series with the standard capacitor as shown in figure 10.

c. **THE EXTERNAL GENERATOR BINDING POSTS.** These two binding posts, mounted on the common terminal board, are labeled EXT. GEN.. The EXT. GEN. binding posts are used to connect an external d-c voltage source or audio oscillator to the bridge.

d. **LR BINDING POSTS.** These two binding posts are marked LR between the posts on the common terminal board. The LR binding posts are used to connect the unknown inductor or resistor to the bridge for measurement.

e. **C BINDING POSTS.** These two binding posts are marked C between the posts on the common terminal board. The C binding posts are used to connect the unknown capacitor to the bridge for measurement.

Note. The binding post of each pair marked LO is the low post of each pair. The unmarked post in each case is the high post of the pair. Standard electrical symbols are engraved between the binding posts used for resistance, inductance, and capacitance measurements to facilitate rapid recognition.

Section II. RESISTANCE, CAPACITANCE, AND INDUCTANCE MEASUREMENTS

Note. This Impedance Bridge is a precision laboratory instrument. It will give excellent service over a long period of time if given reasonable care. For best performance, the operating procedures given in this section should be followed carefully.

10. D-c Resistance Measurements (figs. 2 and 3)

D-c resistance measurements are made as follows:

a. CONNECT:

- (1) Unknown resistance to binding posts marked LR.

b. SET:

- (1) Galvanometer to zero by turning zero adjustment cap after unclamping galvanometer movement.

- (2) CIRCUIT SELECTOR to R - R_{XL}.

- (3) DETECTOR switch to SHUNTED METER.

- (4) GENERATOR switch to 6 VOLTS D.C.

- (5) LRC dial to approximately 1.0.

c. ADJUST:

- (1) LRC DIAL MULTIPLIER to the setting which results in minimum deflection of the galvanometer. Choose that position which leaves the pointer to the left of zero.

- (2) LRC dial to reduce meter reading to within one division of zero

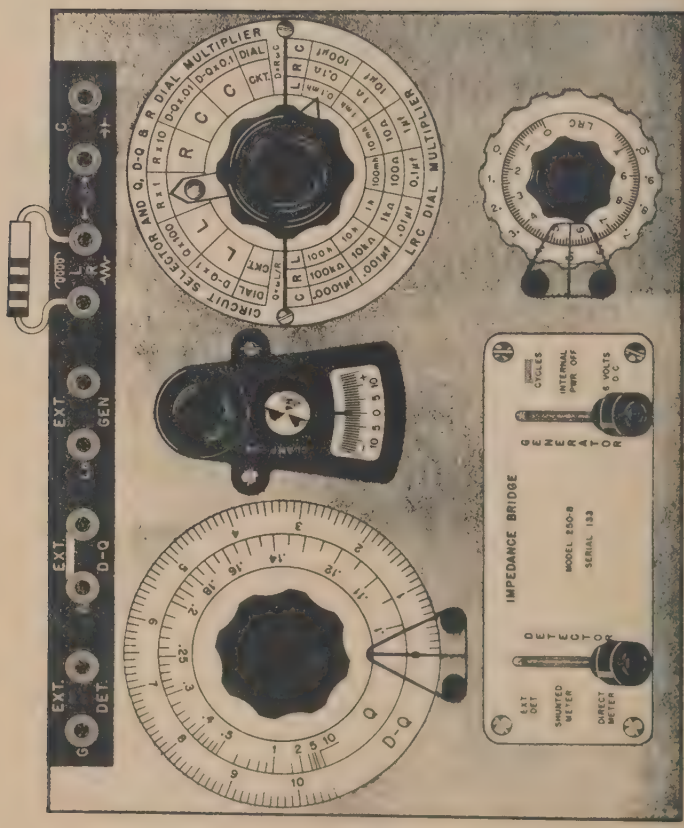


Figure 2. Controls set for measurement of d-c resistance (0.001 ohm to 1 megohm).

before turning the DETECTOR switch to DIRECT METER to make the final LRC dial adjustment.

d. READ:

(1) Value of the unknown resistor on the LRC dial multiplied by the indicated resistance multiplying factor on the LRC DIAL MULTIPLIER. (If the CIRCUIT SELECTOR switch is set at R - Rx10, multiply the reading obtained by 10).

CAUTION: Do not remove the resistor under test before turning the GENERATOR switch to INTERNAL PWR. OFF, and the DETECTOR switch to SHUNTED METER. Do this to prevent possible damage to the bridge galvanometer and resistors.

e. EXAMPLES:

(1) Settings of controls in figure 2 are for the final balance positions of a d-c resistance of 0.556-ohms. Observe the control readings as follows:

CIRCUIT SELECTOR reads R - Rx1
LRC DIAL MULTIPLIER reads..... 0.1 Ω
LRC dial reads..... 5.56

Results: (1) (0.1 Ω) (5.56) = 0.556 ohms.

(2) Settings of controls in figure 3 are for the final balance positions of a d-c resistance of 1.15-megohms. The controls read as follows:

CIRCUIT SELECTOR reads..... R - Rx10
LRC DIAL MULTIPLIER reads..... 100 k Ω
LRC dial 1.15

Results: (10) (100,000 Ω) (1.15) = 1,150,000 ohms = 1.15 megohms.

Note. Higher voltages for greater sensitivity on the higher resistance ranges may be applied to the bridge by connecting a battery or other d-c source of voltage to the EXT. GEN. binding posts. Switch the GENERATOR switch to INTERNAL PWR. OFF to connect the EXT. GEN. binding posts to the bridge circuit. The d-c source must have adequate resistance in series with the bridge to limit the current to a value safely handled by the bridge. The following table indicates the series resistance the voltage source should have:

D-c voltage to be applied	Proper series resistances
6 to 25 volts	10-ohms/volt, or 250-ohms for 25 volts
25 to 100 volts	30-ohms/volt, or 3,000-ohms for 100 v.
100 to 250 volts	100-ohms/volt, or 25,000-ohms for 250 v.

The application of more than 250 volts to the bridge is not recommended.

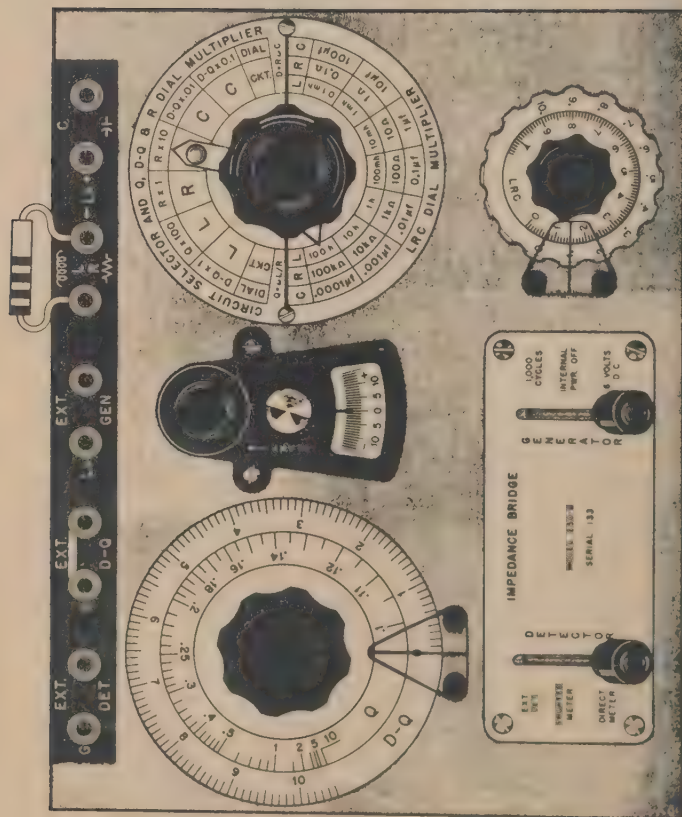


Figure 3. Controls set for measurement of d-c resistance (1 megohm to 11 megohms).

11. Accuracy of D-c Resistance Measurements

a. The error in resistance measurements will not exceed $\pm 0.15\%$ plus one division of the LRC dial on all ranges except the 0.1 ohm range where the error is $\pm 0.35\%$ plus one division on the LRC dial, and the 1 and 11 megohm ranges where the error is $\pm 0.2\%$ plus one division on the LRC dial.

b. The precision of balance, or resolution, possible at very high or very low values of resistance is determined primarily by the internal galvanometer sensitivity and voltage applied to the bridge. The table below gives the approximate percentage of unbalance which will produce 0.2 division deflection on the galvanometer employed in the bridge with the 6 volt internal battery.

LRC DIAL MULTIPLIER setting	Percentage of unbalance for 0.2 division deflection
0.1 Ω	1.0%
1.0 Ω	0.2%
10.0 Ω	0.05%
100.0 Ω	0.05%
1 k Ω	0.07%
10 k Ω	0.4%
100 k Ω	3.0%
100 k $\Omega \times 10$	15.0%

When making measurements on the 0.1 Ω range, corrections should be made for the added resistance of the test leads and for the internal resistance of the bridge. The internal bridge resistance is approximately 0.002 ohms. It can be determined by securely clamping a short, heavy, copper wire, or strap, between the LR binding posts on the bridge. To increase the precision of balance on the low resistance ranges, a more sensitive external galvanometer may be used. The precision of balance on the high ranges may be increased by the use of a more sensitive external galvanometer or by applying higher voltages to the bridge as recommended in paragraphs 10 and 21.

12. Making A-c Resistance Measurements at 1,000 cps. (fig. 4)

A-c resistance measurements are made as follows:

a. CONNECT:

- (1) Unknown resistor to the LR binding posts.

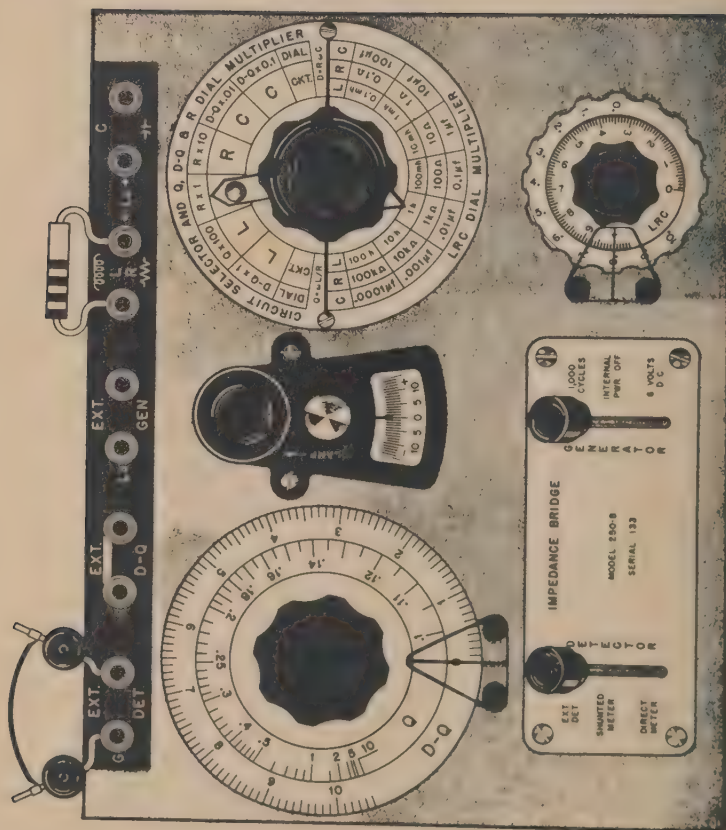


Figure 4. Controls set for measurement of a-c resistance.

(2) Headphones or other null detector to the EXT. DET. binding posts.

b. SET:

(1) DETECTOR switch to EXT. DET.

(2) GENERATOR switch to 1,000 CYCLES. A 1,000 cps note should be heard in the headset.

(3) LRC dial to about 1.0.

c. ADJUST:

(1) LRC DIAL MULTIPLIER knob for minimum sound in the headphones. Adjust the LRC dial until minimum sound or balance is obtained. If a balance cannot be obtained using the LRC dial, readjust the LRC DIAL MULTIPLIER and again adjust the LRC dial for balance.

d. READ:

The value of the unknown resistor on the LRC dial multiplied by the indicated resistance value on the LRC DIAL MULTIPLIER.

e. EXAMPLE:

(1) The settings of controls in figure 4 are for the final balance position of a a-c resistance of 9.0 k Ω .

The controls read as follows:

CIRCUIT SELECTOR reads..... R - Rx1

LRC DIAL MULTIPLIER reads. 1 k Ω

LRC dial reads..... 9.0

Results: (1) (1 k Ω) (9.0) = 9.0 k Ω

13. Accuracy of A-c Resistance measurements

The error of a-c resistance measurements is within $\pm 0.5\%$ + 1 division on the LRC dial from 1 ohm to 100 k-ohms and may increase to $\pm 1\%$ + 1 division on the LRC dial for values of resistance lower than 1 ohm and greater than 100 k ohms.

Note. If a null cannot be obtained or is not sharply defined, it is probable that the resistor under measurement contains considerable reactance. A good balance can be obtained only when the unknown resistor has a small reactance comparable to that of the resistors that make up the bridge circuit. To measure resistors with appreciable reactance, see paragraph 24.

14. Capacitance measurements at 1,000 Cps (fig 5 and 6)

Capacitance measurements at 1,000 cps are made as follows:

a. CONNECT:

(1) Unknown capacitor to C terminals with shield or outside foil

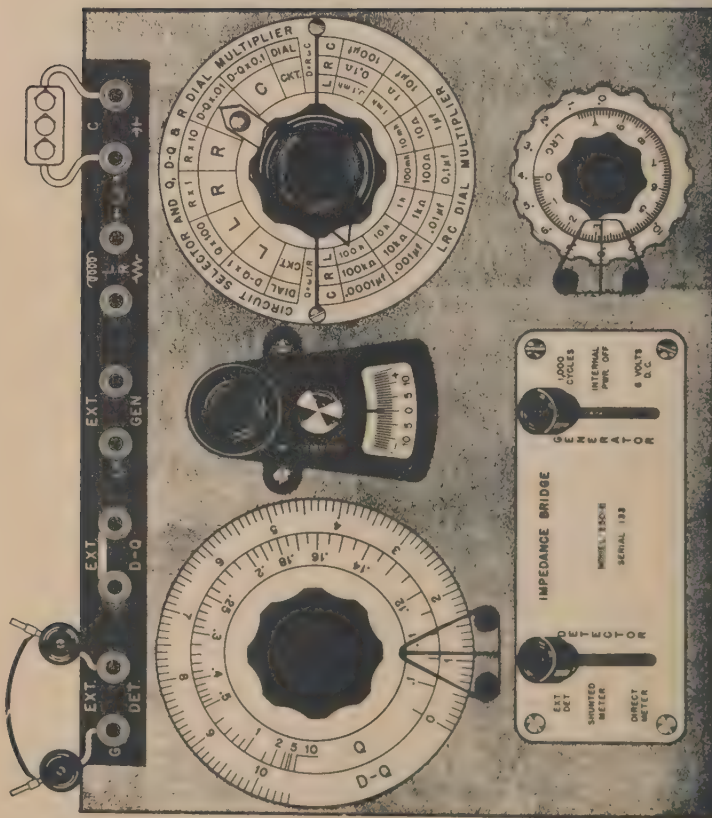


Figure 5. Controls set for measurement of capacitors with dissipation factors from 0.001 to 0.105.

connected to the binding post marked LO.

(2) Headphones or other null indicator to EXT. DET. binding posts.

b. SET:

(1) CIRCUIT SELECTOR to C - DQx.01 for capacitors having dissipation factors (D) up to 0.105 and to C - DQx0.1 for capacitors having dissipation factors up to 1.05.

(2) D-Q dial to mid-scale.

(3) DETECTOR switch to EXT. DET.

(4) GENERATOR switch to 1,000 CYCLES.

(5) LRC dial to approximately 1.0.

c. ADJUST:

(1) LRC DIAL MULTIPLIER for minimum signal on null indicator.

(2) LRC dial and D-Q dial alternately for best null.

d. READ:

(1) Series capacitance (C_s) of unknown capacitor on LRC dial and multiply it by reading on LRC DIAL MULTIPLIER.

(2) Dissipation factor ($D = R_s / X_s = R_s \omega C_s$) of the unknown capacitor on the D-Q scale multiplied by the factor indicated on the CIRCUIT SELECTOR dial.

e. COMPUTE:

(1) Parallel capacitance, $C_p = \frac{C_s}{1 + D^2}$

(2) Series a-c resistance, $R_s = \frac{D}{\omega C_s}$

(3) Parallel a-c resistance, $R_p = \left(\frac{1 + D^2}{D^2} \right) R_s$ or $\frac{1 + D^2}{D \omega C_p}$

f. EXAMPLES:

(1) Settings of controls in figure 5 are for the final balance positions of a capacitor with a dissipation factor (D) of 0.0110 and a capacitance of $832 \mu\mu f$. The controls read as follows:

CIRCUIT SELECTOR reads..... C - DQx.01

LRC DIAL MULTIPLIER reads. $C, 0.0001 \mu f$

LRC dial reads 8.32

D-Q scale reads 1.10

Result: $D = (1.10) (0.01) = 0.0110$

$C = (0.0001 \mu f) (8.32) = 0.000832 \mu f = 832 \mu\mu f$.

(2) Settings of controls in figure 6 are for the final balance positions of a capacitor with a dissipation factor (D) of 0.910 and a capacitance of $109.3 \mu f$. The controls read as follows:

CIRCUIT SELECTOR reads..... C - DQx0.1

LRC DIAL MULTIPLIER reads.. $C, 10 \mu f$

LRC dial reads..... 10.93

D-Q scale reads..... 9.10

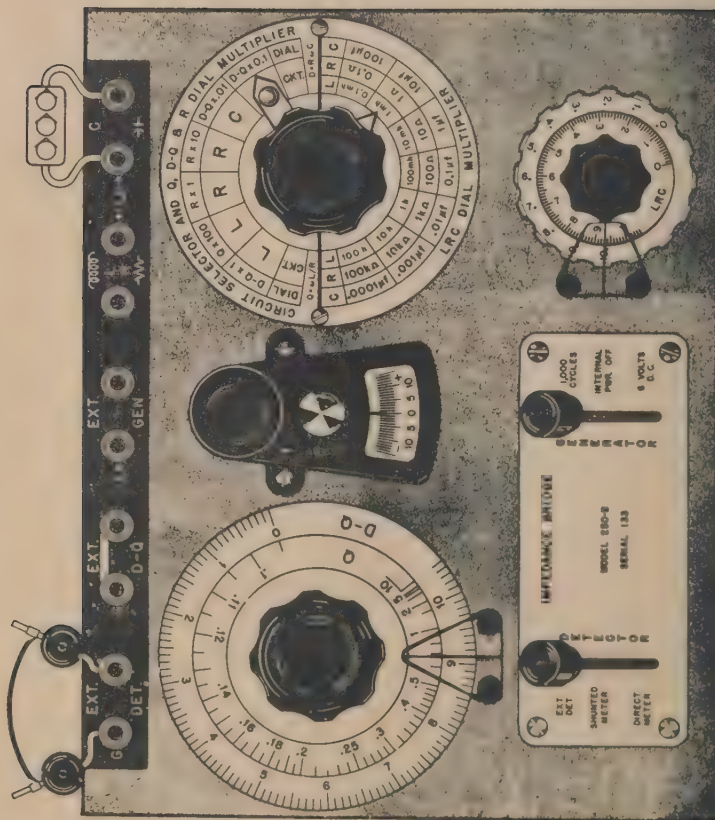


Figure 6. Controls set for measurement of capacitors with dissipation factors from 0.1 to 1.05.

Results: $D=(0.1)(9.10)=0.910$
 $C=(10\mu f)(10.93)=109.3\mu f.$

15. Accuracy of Capacitance Measurements at 1,000 cps

a. The capacitance error is $\pm 0.5\%$ plus one division on the inner LRC dial between $100\mu\mu f$ and $100\mu f$, and may increase to 2% at larger values of capacitance. For smaller values of capacitance, the error will be within $2\mu\mu f$ if corrections are made for the zero capacitance of the bridge and test leads. For further discussion of capacitance errors see paragraph 41.

b. The zero capacitance of the bridge may be measured by leaving the C terminals open and is about $2.5\mu\mu f$.

c. The capacitance of the bridge plus the test leads may be determined by disconnecting the lead connected between the C (high) binding post and the capacitor under test. Take care not to disturb the relative position of the leads.

16. Accuracy of the Dissipation Factor Measurement

Dissipation factor error is $\pm(7\% + 0.0025)$ for capacitors greater than $0.01\mu f$. Approximately 0.005 should be subtracted from the dissipation factor readings on the $0.001\mu f$ range and 0.05 subtracted from the readings on the $0.0001\mu f$ range to compensate for the small residual capacitances across the 0.1 megohm and 1 megohm ratio arms. For a more accurate determination of these correction factors, see paragraph 41 b.

For capacitances less than $1,000\mu\mu f$ measured on the $0.0001\mu f$ range, correction must be made for the zero capacitance of the bridge (C_o) and its dissipation factor (D_o) by the following equation:

$$D_e = \frac{D_u C_u - D_o C_o}{C_u - C_o}$$

The subscript "u" refers to the bridge readings with the unknown connected, and the subscript "o" to the readings with the unknown disconnected.

17. Inductance Measurements at 1,000 Cps (figs. 7 and 8)

a. CONNECT:

(1) Unknown inductor to binding posts marked L.R with shield, if any, connected to the binding post marked L.O.

(2) Headphones or other null detector to EXT. DET. binding posts.

b. SET:

(1) CIRCUIT SELECTOR to L - DQx1 for an inductor having a

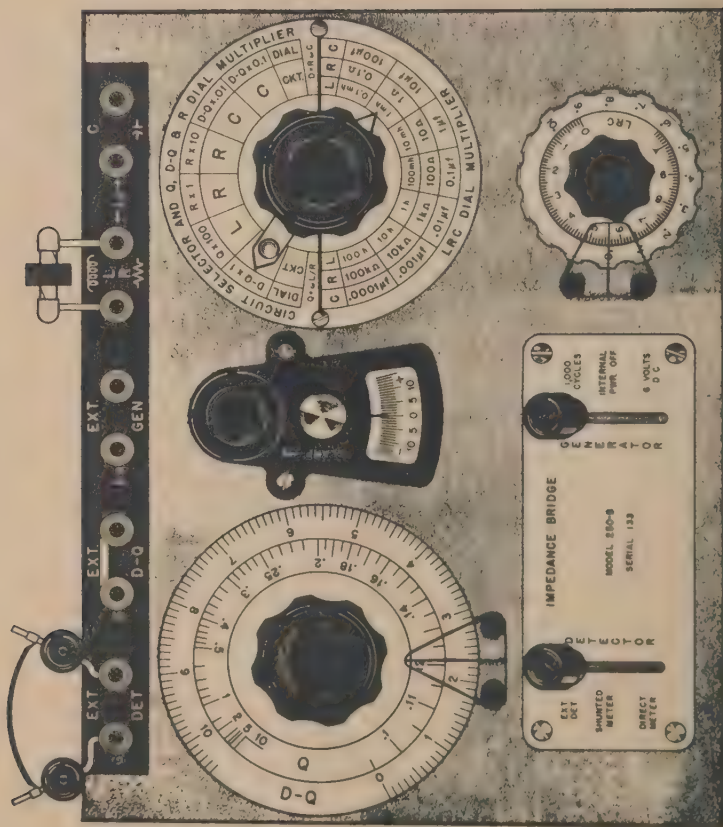


Figure 7. Controls set for measurement of inductors with storage factors from 0.02 to 10.5.

storage factor (Q) less than 10.5, and to L -- Qx100 for an inductor having a storage factor between 10 and 1,000.

(2) D-Q or Q dial to mid-scale.

(3) DETECTOR switch to EXT. DET.

(4) GENERATOR switch to 1,000 CYCLES

(5) LRC dial to approximately 1.0.

c. ADJUST:

(1) LRC DIAL MULTIPLIER for minimum signal on null indicator.

(2) LRC dial and D-Q dial alternately for best null.

d. READ:

(1) Inductance of unknown inductor on LRC dial multiplied by the reading of the LRC DIAL MULTIPLIER. This inductance is series inductance L_s when the CIRCUIT SELECTOR switch is set at DQx1 (Maxwell bridge, fig. 11), and parallel inductance L_p when the CIRCUIT SELECTOR switch is set at Qx100 (Hay bridge, fig. 12).

(2) Storage factor $Q = X_s/R_s = \omega L_s/R_s$ of unknown inductor on the D-Q or Q scale multiplied by the factor indicated on the CIRCUIT SELECTOR.

e. COMPUTE:

(1) Parallel inductance, $L_p = \left(\frac{1+Q^2}{Q^2} \right) L_s$

(2) Series inductance, $L_s = \left(\frac{Q^2}{1+Q^2} \right) L_p$

(3) Series a-c resistance, $R_s = \omega L_s / Q$.

(4) Parallel a-c resistance, $R_p = Q\omega L_p = (1+Q^2) R_s$

f. EXAMPLES:

(1) Settings of the controls in figure 7 are for the final balance positions of an inductor with a storage factor (Q) of 2.30, and an inductance of 0.56 mh. The controls read as follows:

CIRCUIT SELECTOR reads..... DQx1

LRC DIAL MULTIPLIER reads..... L, 1 mh

LRC dial reads..... 0.56

D-Q dial reads 2.30

Results: $Q = (1) (2.30) = 2.30$

$L = (1 \text{ mh}) (0.56) = 0.56 \text{ mh}$.

(2) Settings of the controls in figure 8 are for the final balance positions of an inductor with a storage factor (Q) of 32, and an inductance of 9.99 henrys. The controls read as follows:

CIRCUIT SELECTOR reads..... L -- Qx100

LRC DIAL MULTIPLIER reads..... L, 1 h

LRC dial reads 9.99

Q dial reads 0.32

Results: $Q = (100) (0.32) = 32.0$

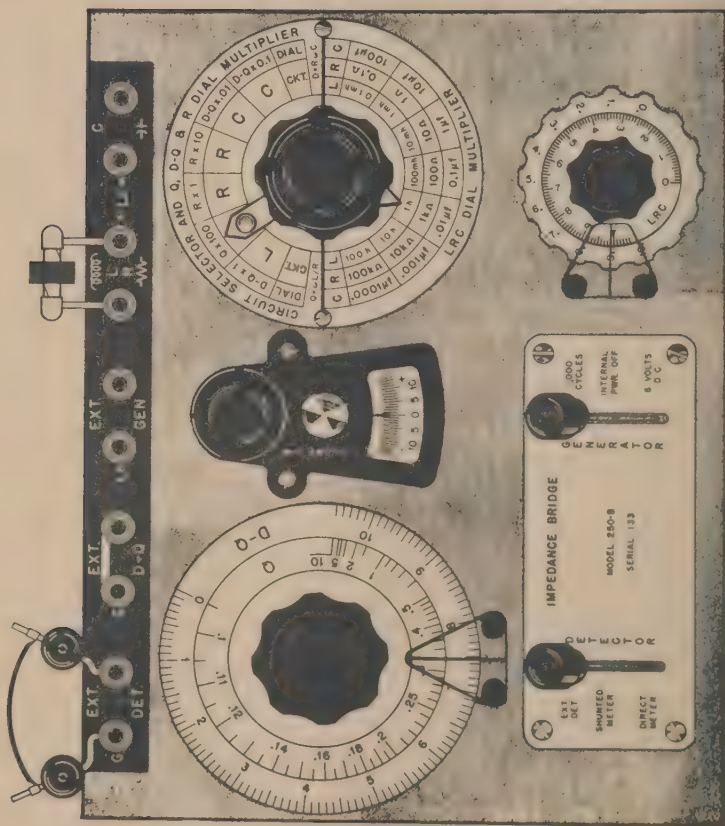


Figure 8. Controls set for measurement of inductors with storage factors from 10 to 1000.

$$L = (1 \text{ henry}) (9.99) = 9.99 \text{ henrys.}$$

Notes:

(1) Series inductance (L_s) refers to the effective inductance of a coil at a given frequency when it is considered to be in series with an a-c resistance (R_s). Parallel inductance (L_p) refers to the effective inductance of a coil at a given frequency when it is considered to be in parallel with an a-c resistance (R_p). Series inductance (L_s) is the value most commonly used. The Maxwell bridge reads L_s directly. The Hay bridge reads L_p directly, but L_p and L_s are approximately equal if the Q of the inductor is greater than 10 (see equations 1 and 2 in e above).

(2) Place the inductor at least a foot away from the bridge to prevent errors introduced by the coupling of the internal microphone hummer field and the inductor field.

18. Accuracy of Inductance Measurements at 1,000 Cps

The inductance error is $\pm 1\% \pm 1$ division on the LRC dial between 100 μ h and 10 henrys. At higher inductance, the error may increase to $\pm 10\%$ because of the increasing effect of the capacitances to ground associated with the inductor and the bridge arms. Below 100 μ h, the error will be within 2 μ h if corrections are made for the zero inductance of the bridge and the test leads. For further discussion of inductance errors, see paragraph 41.

19. Accuracy of Storage Factor Measurements

Storage factor error expressed in terms of its reciprocal (D) is $\pm (7\% \pm 0.0025)$ up to 10 henrys. This increases to $\pm (7\% \pm 0.055)$ at 1,000 henrys. The increasing error appearing as the inductance increases is caused by the small residual capacitances across the high impedance ratio arms. For further discussion of storage factor errors, see paragraph 41 c.

Section III. MISCELLANEOUS BRIDGE APPLICATIONS

20. General

Additional applications of the Impedance Bridge are covered in this section. If necessary, consult the step-by-step procedures covering measurements of resistance, capacitance, and inductance in Section II for further information.

CAUTION: Persons who do not thoroughly understand bridge theory should not attempt to use the bridge for applications given in this

section. Operators who do not have sufficient technical background probably will be unable to obtain satisfactory results and may seriously damage the bridge.

21. Use of External D-c Generator

a. An external battery may be connected to the bridge for greater sensitivity on d-c resistance ranges. The bridge circuit used for resistance measurements is shown in figure 9.

CAUTION: The voltages applied to the bridge must not exceed the limits of safe operation (40 degrees Centigrade temperature rise) for the bridge ratio arms. The maximum voltages and currents are given in the following tables.

Control	Ratio arm (ohms)	E max. (volts)	I max. (ma.)
CIRCUIT SELECTOR	B		
R x 1	10,000	71	7.1
R x 10	1,000	23	23.0

Control	Ratio arm (ohms)	E max. (volts)	I max. (ma.)
LRC DIAL MULTIPLIER (row R)	A		
0.1	1	0.71	710.00
1	10	2.30	230.00
10	100	7.10	71.00
100	1,000	23.00	23.00
1 k	10,000	71.00	7.10
10 k	100,000	230.00	2.30
100 k	1,000,000	250.00	0.25

Control	Ratio arm (ohms)	E max. (volts)	I max. (ma.)
LRC RHEOSTAT	N		
LRC Decade Resistors	10 at 1,000 ohms	23	23
LRC Rheostat	0 to 1,050 ohms	89	85

These ratings will not be exceeded if the d-c source has adequate resistance in series with the bridge to limit the current to safe values. The following table indicates the value of resistance to place in series with the voltage source.

D-c voltage to be applied	Proper series resistance
6 to 25 volts	10-ohm/volt, or 250-ohms for 25 volts
25 to 100 volts	30-ohm/volt, or 3,000-ohms for 100 volts
100 to 250 volts	100-ohm/volt, or 25,000-ohms for 250 volts

The application of more than 250 volts to the bridge is not recommended.

b. To use an external battery with the bridge, proceed as follows:

(1) *Connect:* External battery with proper series resistance to EXT. GEN. binding posts. The positive terminal of the battery is connected to the EXT. GEN. binding post marked I.O to give the same direction of galvanometer deflection as that obtained with the internal battery.

(2) *Set:* GENERATOR switch to INTERNAL PWR. OFF to connect the EXT. GEN. binding posts to the bridge.

(3) Proceed to make the desired d-c resistance measurements as outlined in paragraph 10.

22. Use of External A-c Generator

a. An external a-c generator (audio oscillator) may be connected to the bridge for making a-c resistance, capacitance, and inductance measurements at other than 1 kc. The bridge circuits used for these measurements are given in figures 9, 10, 11, and 12.

CAUTION: The voltage applied to the bridge must not exceed the limits of safe operation (40 degrees Centigrade temperature rise) for the bridge components. These limits for the ratio arms are given in the table in paragraph 21. The limits for the D and Q rheostats are given in the table below.

Rheostat	R max. (ohms)	E max. (volts)	I max. (ma.)	R (k Ω)
D	166	35	210	D-Q reading x 0.01592
D	1,670	110	68	D-Q reading x 0.1592
Q	16,750	350	21	D-Q reading x 1.5920

The maximum voltage rating for the 0.1 μ f standard capacitor (C-2 in figures 10, 11, and 12 is 350 volts up to 20 kc. An oscillator having a maximum output of 0.5 watts can safely be used under all conditions.

b. To use an external a-c generator with the bridge, proceed as follows:

(1) *Connect:* An external generator to EXT. GEN. binding posts with the "low" binding post of the generator (binding post having the greatest capacitance to ground) to the EXT. GEN. binding post marked LO.

(2) *Set:* GENERATOR switch to INTERNAL PWR. OFF to connect the EXT. GEN. binding posts to the bridge.

(3) Proceed to make the desired a-c resistance, capacitance, or inductance measurements as outlined in paragraphs 12, 14, and 17. The resistance, capacitance, and inductance readings are essentially independent of frequency from 60 cycles to 10 kc. The dissipation factor (D) and the storage factor (Q) readings are dependent on frequency as outlined in paragraph 5 d.

c. External oscillators usually have considerable ground capacitance associated with their terminals. As the junction of the LRC rheostat arm and the standard capacitor arm is connected to the metal bridge case, the ground capacitance of the external generator falls across these arms if the bridge case is grounded. The capacitance across the standard capacitor arm will cause the inductance and capacitance readings to be low. The fractional error in capacitance and inductance reading is the ratio of the ground capacitance placed across the standard capacitor to the capacitance of the standard capacitor. The ground capacitance across the LRC rheostat will cause the bridge to read low on dissipation factor (D), and high on the storage factor (Q) readings. The error in the dissipation factor reading is equal to the product $R\omega C$, where R is the resistance of the LRC rheostat (LRC dial setting x 1,000 ohms), and C is the ground capacitance placed

across the LRC rheostat. The capacitance to ground of a typical battery operated oscillator is approximately 30 to 50 $\mu\mu\text{f}$, and will make the bridge read 0.03% to 0.05% low on capacitance and inductance measurements. The capacitance to ground of a typical a-c operated oscillator is approximately 300 to 500 $\mu\mu\text{f}$, and makes the bridge read 0.3% to 0.5% low. The increase in ground capacitance for the a-c operated oscillator is caused by the interwinding capacitance of the power supply transformer.

These errors can be reduced by use of a shielded isolation transformer between the oscillator and the bridge. This transformer will eliminate the effect of ground capacitance of the oscillator, but will also introduce similar capacitance effects of its own. Usually the interwinding capacitance of such a shielded transformer will not be greater than 50 to 75 $\mu\mu\text{f}$, and will introduce a maximum error of 0.075%.

If a shielded bridge transformer is not available, the bridge itself may be isolated from ground by placing it at least a foot away from any metallic object on a wooden bench or other non-metallic support. Any wires connected to ground or having high capacity to ground should be disconnected from the bridge. In this manner, the capacitance of the metal bridge cabinet to ground may be reduced to below 100 $\mu\mu\text{f}$, and the bridge error will not exceed 0.1%. Small hand capacitance effects may be noted with this arrangement as the capacitance to ground introduced by touching exposed portions of the bridge will lower the reading slightly.

For further discussion of these errors, see paragraph 41.

23. Measurement of A-c Resistance at Frequencies Other than 1 KC

The 1,000 cycle tone used for the a-c resistance measurements as described in paragraph 12 is generated by the microphone hummer in the bridge. If a-c resistance is to be measured at a different frequency, proceed as follows:

a. CONNECT:

- (1) External generator (par. 22) to the EXT. GEN. binding posts.
- (2) Headset or other null indicator to the EXT. DET. binding posts.

b. SET:

- (1) GENERATOR switch to INTERNAL PWR. OFF.
- (2) DETECTOR switch to EXT. DET.

c. Measure a-c resistance as outlined in paragraph 12. If a good null balance cannot be obtained, proceed as outlined in paragraph 24. For errors at high frequencies, refer to the equations in paragraph 41.

24. Measurement of A-c Resistance with Reactance

To obtain a sharp null when measuring resistances having appreciable reactance, connect a good quality, calibrated, variable capacitor across the appropriate bridge arm, or bridge component, designated in the text and table below.

a. To measure resistances having appreciable associated capacitance, e.g., electrolytic cells, connect the variable capacitor across the A or N arm of the bridge as indicated in the table.

b. To measure resistances having appreciable inductive reactance, e.g., some types of layer wound resistors, connect the variable capacitor across the B arm as indicated in the table. The storage factor of the unknown impedance is of the form $R \times C$. Where R is the resistance of the arm across which the capacitor is placed.

c. Unknown resistances having appreciable associated inductive reactance can also be measured by connecting the capacitor across the unknown resistance to make a parallel resonance bridge, or connect the variable capacitor in series with the unknown resistance to make a series resonance bridge. The parallel or series inductance is calculated from the formula $L = 1/\omega^2 C$.

d. TABLE FOR PROPER PLACEMENT OF VARIABLE CAPACITOR FOR DETERMINING REACTANCE COMPONENT OF AN A-C RESISTANCE.

Bridge arm	Terminal connection for capacitor	Resistance	Q	Reactance
A	$C_{(high)}$ and C_{LO}	Parallel	$R_a \omega C_a$	— or C
N	$LR_{(high)}$ and G	Parallel	$R_n \omega C_n$	— or C
B	$C_{(high)}$ and G	Series	$R_b \omega C_b$	+ or L
U	$LR_{(high)}$ and LR_{LO}	Parallel	$R_u \omega C_u$	+ or L
U	In series with unknown.	Series	$\frac{1}{R_u \omega C_u}$	+ or L

e. The a-c resistance with reactance measurements are made as follows:

(1) Connect:

(a) Unknown resistor to LR binding posts.

(b) Headphones or other null indicating device to EXT. DET. binding posts.

(c) Variable capacitor to binding posts indicated in the above

text and table.

(2) Set:

- (a) DETECTOR switch to EXT. DET.
- (b) GENERATOR switch to 1,000 CYCLES. A 1,000 cps tone should be heard in headset.
- (c) LRC dial to about 1.0.

(3) Adjust: The LRC DIAL MULTIPLIER knob for minimum sound in the headphones. Alternately adjust the LRC dial and the variable capacitor until minimum sound or balance is obtained. If a balance cannot be obtained using the LRC dial and variable capacitor, readjust the LRC DIAL MULTIPLIER and again adjust the LRC dial and variable capacitor for balance.

(4) Read and compute: The value of the unknown resistor on the LRC dial multiplied by the indicated resistance value on the LRC DIAL MULTIPLIER. Compute the storage factors by the equations in the Q column of the above table.

25. Measurement of Parallel Capacitance and Resistance of a Capacitor

a. To measure parallel capacitance and resistance of a capacitor, proceed as follows:

(1) CONNECT:

- (a) Unknown capacitor to C. binding posts with shield or outside foil connected to the binding post marked LO.
- (b) Headphones or other null indicator to EXT. DET. binding posts.
- (c) Calibrated rheostat or decade box across the C (high) binding post and any binding post marked G.

(2) SET:

- (a) CIRCUIT SELECTOR to C - DQx.01 or C - DQx0.1.
- (b) D-Q dial to zero.
- (c) DETECTOR switch to EXT. DET.
- (d) GENERATOR switch to 1,000 CYCLES.
- (e) LRC dial to approximately 1.0.

(3) ADJUST:

- (a) LRC DIAL MULTIPLIER for minimum signal on null indicator.
- (b) LRC dial and external calibrated rheostat alternately for best null.

(4) READ:

(a) Parallel capacitance (C_p) of unknown capacitor on LRC dial and multiply it by reading on LRC DIAL MULTIPLIER.

(b) Resistance on external calibrated rheostat.

(5) COMPUTE: Parallel resistance (R_p) by the following formula;

$$R_p = \frac{R_e R_a}{R_n}$$

where R_e is the value of the external rheostat, R_a the resistance of ratio arm A controlled by the LRC DIAL MULTIPLIER when the bridge is balanced (see table, par. 21 a.), and R_n is the reading of the LRC dial multiplied by 1,000.

26. Measurement of Three Terminal Capacitors

The direct capacitance of a three terminal capacitor is determined as follows:

a. CONNECT:

(1) Two terminals of the unknown capacitor to the C binding posts of the bridge.

(2) The third terminal to any binding post marked G.

Note. This places the direct capacitance between the terminals connected to C_{LO} and G binding posts across the detector, and the direct capacitance between the C (high) and G binding posts across the standard 0.1 μ f capacitor. The capacitance across the detector will not disturb the measurement, while the capacitance across the standard capacitor will cause the bridge to read low. The bridge will read low by the ratio of the added capacitance to the standard capacitor. For example, if the direct capacitance across the 0.1 μ f standard capacitor is 0.0001 μ f, the bridge will read 0.1% low.

b. ADJUST: Proceed with capacitance measurements as outlined in paragraph 14.

27. D-c Polarizing Voltage for Electrolytic Capacitors

In the capacitance measurement of an electrolytic capacitor a stabilizing (forming) voltage must be applied to the capacitor before an accurate balance can be obtained on a bridge. When the internal hummer is used, a d-c polarizing battery of not over 200 volts is placed in series with the capacitor being measured.

a. CONNECT:

(1) Positive terminal of battery to the C binding post marked LO.

(2) Negative terminal of battery to negative terminal of the capacitor being measured.

(3) Positive terminal of capacitor to the C (high) binding post.

b. ADJUST: Proceed with capacitance measurements as outlined in paragraph 14.

Notes:

(1) Leakage current can be measured by placing a milliammeter in series with the battery between the positive battery terminal and the C_{LO} binding post.

(2) If an external oscillator is used, the battery is placed as indicated above or in series with the external oscillator. The capacitance of the battery to ground will be added to whichever side of the oscillator it is connected.

28. Measurement of Terminal Capacitance of Inductors

The terminal capacitance between the terminals of an inductor and its shield are measured as follows:

a. CONNECT:

(1) Terminal whose capacitance is to be measured to the C binding post marked LO.

(2) Shield to the C (high) binding post.

(3) The remaining terminal of the inductor to any binding post marked G.

b. ADJUST: Proceed from here according to capacitance measurements outlined in paragraph 14.

c. The capacitance of the other terminal is measured by reversing the two inductor connections, leaving the shield connected to the C (high) binding post and proceeding the same as above.

Notes:

1. In the above connection instructions for the measurement of the terminal capacitance of an inductor, the remaining terminal capacitance and the ground capacitance of the shield fall across the standard $0.1\mu f$ capacitor. The error introduced is usually negligible as terminal capacitances in shielded transformers rarely exceed $500\mu\mu f$. This introduces a maximum error of only 0.5%.

29. Measurement of Series or Parallel Inductance and Resistance of an Inductor

a. Series inductance L_s is the effective inductance when the losses in the inductor are represented as a resistance R_s in series with the inductor. Parallel inductance L_p is the effective inductance when the losses in the inductor are represented as a resistance R_p in parallel with the inductor. The storage factor Q is the ratio of the series react-

ance to the series resistance, or the ratio of the parallel resistance to parallel reactance. Storage factor Q is the reciprocal of the dissipation factor D . These relationships are summarized in the following equation:

$$Q \equiv X_s/R_s = \omega L_s/R_s = \bar{R}_p/X_p = R_p/\omega L_p = 1/D$$

b. Series inductance L_s and storage factor Q can be measured by setting the CIRCUIT SELECTOR switch to $L - D \times 1$ (Maxwell bridge circuit, figure 11) and proceeding as outlined in paragraph 17. The series resistance, R_s , can be computed from formula 3 in paragraph 17 e. The range of the D - Q rheostat can be extended as described in paragraph 32.

c. Parallel inductance L_p and storage factor Q can be measured by setting the CIRCUIT SELECTOR switch to $L - Q \times 100$ (Hay bridge circuit, figure 12, and proceeding as outlined in paragraph 17. The parallel resistance R_p can be computed from formula 4 in paragraph 17 e. The range of the Q rheostat may be extended as described in paragraph 32.

30. Measurement of Iron Core Inductors with D-C Magnetizing Current

To measure an inductor with d-c magnetizing current flowing, proceed as follows:

a. CONNECT:

(1) A choke coil of low d-c resistance and several henrys inductance in series with a rheostat across the EXT. DET. binding posts.

(2) A headset or other null indicator across the EXT. DET. binding posts.

(3) A battery and a milliammeter in series with the unknown inductor terminal connected to the LR binding post marked LO.

(4) The remaining inductor terminal to the LR (high) binding post.

b. READ:

(1) The inductance of the unknown inductor as outlined in paragraph 17. The resistance and inductance of the battery and milliammeter will generally be negligible compared to the resistance and inductance of the inductor under test.

(2) The d-c magnetizing current in the inductor from the milliammeter scale.

CAUTION: The d-c current must not exceed 23 milliamperes in the LRC decade-rheostat (paragraph 21).

Note. There are two current paths to be considered in the Hay inductance bridge (fig. 12) when the internal hummer is used as the

bridge generator. One of these current paths is from the battery through the meter, the unknown inductor, the LRC decade-rheostat, and back through the low d-c resistance choke and rheostat to the battery. The other current path is from the battery through the meter, the unknown inductor, the hummer secondary coil (100 ohms for LRC DIAL MULTIPLIER positions of 100 mh through 100 h. 1 ohm for LRC DIAL MULTIPLIER positions of 0.1 mh, 1.0 mh, and 10 mh) and back through ratio arm A to the battery. This second current path may be eliminated by the use of an external generator (par. 22) in series with a blocking capacitor.

An additional current path is introduced in the Maxwell inductance bridge (fig. 11) by the Q rheostat R-25.

Care should be taken not to exceed the current ratings of the bridge resistors and rheostats given in paragraphs 21 and 22.

31. Determining Resonant Frequency of an Inductor or Tuned Circuit

To determine the resonant frequency of a tuned circuit or inductor proceed as follows:

a. CONNECT:

(1) Unknown inductor or tuned circuit to the LR binding posts with the shield, if any, connected to the binding post marked LO.

(2) A continuously variable audio oscillator to the EXT. GEN. binding posts. See paragraph 22 for precautions in the use of an external generator.

(3) Headphones or other suitable null indicator to the EXT. DET. binding posts. An audio amplifier in conjunction with an output meter or oscilloscope is necessary for precise measurements.

b. SET:

(1) CIRCUIT SELECTOR switch to R - Rx1.

(2) GENERATOR switch to INTERNAL PWR. OFF.

(3) DETECTOR switch to EXT. DET.

(4) LRC dial to approximately 1.0.

c. ADJUST:

(1) LRC DIAL MULTIPLIER for minimum signal on null indicator.

(2) LRC dial and external oscillator frequency alternately for best null.

d. READ:

(1) Resonant frequency of the tuned circuit or inductor from the external oscillator dial.

(2) Parallel resistance of the unknown impedance from the LRC dial

multiplied by the indicated R scale value on the LRC DIAL MULTIPLIER.

Note. The capacitance across the LR binding posts due to bridge wiring is added to the capacitance of the impedance being measured and lowers the resonant frequency. The bridge wiring capacitance is approximately 2 to 3 micromicrofarads.

32. Measurement of Dissipation Factor and Storage Factor at Frequencies Other than 1 kc.

Note. The error of $\pm(7\%+0.0025)$ in dissipation factor and storage factor readings varies directly with frequency except that the average error will never be less than 1% (error of adjustment of the D, D-Q, and Q rheostats).

a. GENERAL. The calibration of the LRC dial is independent of the frequency used in making measurements. Dissipation factor and storage factor, however, depend on frequency and the D-Q, and Q scales are direct reading only at 1 kc. All dissipation or storage factor readings on the black D-Q scale must be multiplied by the frequency in kc. to obtain the correct values. Storage factor readings on the red Q scale must be divided by the frequency in kc. to obtain the correct values. At frequencies lower than 1 kc, the D-Q and Q scales do not overlap. At frequencies higher than 1 kc, the ranges of the rheostats are more than sufficient to overlap.

b. RESISTOR VALUES FOR USE IN D and Q RANGE EXTENSION.

A calibrated rheostat or decade box is connected to the EXT. D-Q binding posts (remove shorting bar) to extend the range of the bridge rheostats. This will provide sufficient resistance for the overlapping of ranges on the D-Q and Q scales when dissipation factor and storage factor are measured at frequencies below 1 kc. For storage factors below 10, the external resistance must be connected to the C (high) binding post and any binding post marked G. Short the EXT. D-Q binding posts, set the D-Q dial at zero, and set the CIRCUIT SELECTOR switch to L - $Q \times 100$.

The resistance values required for given values of dissipation factor and storage factor at typical frequencies are given in the following table. These values are the total resistance in series or in parallel with the standard capacitor in bridge arm B, figures 10, 11, and 12.

CIRCUIT SELECTOR SETTINGS

1	2	3	4	5
Frequency (kc)	C - DQx.01 R for D=0.1 (kΩ)	C - DQx0.1 R for D=1 (kΩ)	L - Qx100 R for Q= 10 or more (kΩ)	L - Qx100 R for Q= 10 or less (kΩ)
0.10	1.592	15.920	1.592	159.20
0.20	0.796	7.960	0.796	79.60
0.50	0.318	3.184	0.318	31.840
2.00	0.080	0.796	0.080	7.960
5.00	0.032	0.318	0.032	3.184
10.00	0.016	0.160	0.016	1.592

Notes:

1. Column 1 gives typical frequencies at which D or Q may be measured.

2. Column 2 gives the resistance in kilohms necessary for a dissipation factor of 0.1 at the given frequencies. This resistance may be computed for any other frequency or dissipation factor from the formula:

$$R(k\Omega) = 1.592 D / f (kc).$$

3. Column 3 gives the resistance in kilohms necessary for a dissipation factor of 1.0 at the given frequencies. The resistance may be computed for any other frequency or dissipation factor from the formula given in Note 2 above.

4. Column 4 gives the resistance in kilohms necessary for a storage factor of 10 at the given frequency. Larger values of storage factors require less resistance. The proper resistance value may be computed for any other frequency or storage factor from the formula:

$$R(k\Omega) = 1.592 / Qf (kc).$$

5. Column 5 gives the resistance in kilohms necessary for a storage factor of 10 at the given frequencies. This resistance must be connected to the C (high) binding post and any binding post marked G. The CIRCUIT SELECTOR should be set at L - Qx100, the shorting bar should remain connected across the EXT. D-Q binding posts and the Q dial set at 1,000. The proper resistance value may be computed for any other frequency or storage factor from the formula:

$$R(k\Omega) = 1.592 Q / f (kc).$$

c. MEASUREMENT OF DISSIPATION FACTOR BELOW 1 KC. Although the ranges of the dissipation factor rheostats do not overlap below 1 kc, often the dissipation factor of the unknown capacitor will lie within the limited range of the bridge rheostats. Try to secure a null first with the bridge rheostats. If a null can be obtained, multiply the D-Q scale reading by the frequency in kc to obtain the correct value. If a null cannot be obtained, proceed as outlined below.

(1) *Connect:*

- (a) An external audio oscillator to the EXT. GEN. binding posts. See paragraph 22 for precautions in the use of an external generator.
- (b) A calibrated rheostat or decade box to the EXT. D-Q binding posts after removing the shorting bar. Use column 2 or 3 of the table in *b* above to determine the necessary maximum resistance for the external rheostat or decade box.
- (c) Headphones or other null indicator to the EXT. DET. binding posts.
- (d) Unknown capacitor to C terminals with shield or outside foil connected to the LO binding post.

(2) *Set:*

- (a) CIRCUIT SELECTOR to C - DQx.01 or C - DQx0.1.
- (b) D-Q dial to zero.
- (c) GENERATOR switch to INTERNAL PWR. OFF.
- (d) DETECTOR switch to EXT. DET.
- (e) LRC dial to approximately 1.0.

(3) *Adjust:*

- (a) LRC DIAL MULTIPLIER for minimum signal on null indicator.
- (b) LRC dial and external rheostat alternately for best null.

(4) *Read:*

- (a) Series capacitance (C_s) of unknown capacitor on LRC dial and multiply it by the reading on the LRC DIAL MULTIPLIER.
- (b) Resistance of external rheostat across EXT. D-Q binding posts.

(5) *Compute:* Dissipation factor of unknown capacitor using the formula:

$$D = 0.628 fR$$

where f is the frequency in kilocycles and R is the resistance of the

external rheostat in kilohms.

CAUTION: Be sure to connect shorting bar across the EXT. D-Q binding posts after completing the measurement.

d. MEASUREMENT OF STORAGE FACTOR BELOW 1 KC. Although the ranges of the storage factor rheostats do not overlap below 1 kc, often the storage factor of the unknown inductor will lie within the limited range of the bridge rheostats. Try to secure a null first with the bridge rheostats. If a null can be obtained, multiply the Q reading on the black D-Q scale by the frequency in kc to obtain the correct value. Divide the Q reading on the red scale by the frequency in kc to obtain the correct value. If null cannot be obtained on either scale, proceed as outlined below.

(1) Connect:

- (a) An external audio oscillator to the EXT. GEN. binding posts. See paragraph 22 for precautions in the use of an external generator.
- (b) A calibrated rheostat or decade box to the EXT. D-Q binding posts after removing the shorting bar. Refer to column 4 of the table in *b* above to determine the necessary maximum resistance for the Hay inductance bridge (fig. 12). This bridge circuit is used for inductors having storage factors ranging from 10 to 1,000. If the storage factor is below 10, leave the shorting bar connected across the EXT. D-Q binding posts and connect the external rheostat to the C (high) binding post and any binding post marked G. Refer to column 5 of the table in *b* above to determine the necessary maximum resistance for the Maxwell inductance bridge (fig. 11). This bridge circuit is used for inductors having a storage factor below 10.
- (c) Headphones or other null indicator to the EXT. DET. binding posts.
- (d) Unknown inductor to LR binding posts with shield connected to the LO binding posts.

(2) Set:

- (a) CIRCUIT SELECTOR TO L - $Q \times 100$
- (b) D-Q dial to 10.5.
- (c) GENERATOR switch to INTERNAL PWR. OFF.
- (d) DETECTOR switch to EXT. DET.
- (e) LRC dial to approximately 1.0.

(3) Adjust:

- (a) LRC DIAL MULTIPLIER for minimum signal on null in-

indicator.

(b) LRC dial and external rheostat alternately for best null.

(4) Read:

- (a) Inductance of unknown inductor on LRC dial and multiply it by the reading on the LRC DIAL MULTIPLIER. This inductance is parallel inductance (L_p) if the external rheostat is across the EXT. D-Q binding posts. The inductance is series inductance (L_s) if the external rheostat is connected across the C (high) and G binding posts.
- (b) Resistance of external rheostat across EXT. D-Q binding posts or across the C (high) binding post and any binding post marked G.

(5) Compute: Storage factor of the unknown inductor. Use the formula:

$$Q = 1.592 / fR$$

where f is the frequency in kc and R is the resistance of the external rheostat in kilohms if the external rheostat is connected across the EXT. D-Q binding posts. If the external rheostat is connected across the C (high) and G binding posts use the formula:

$$Q = 0.628 fR$$

where f is the frequency in kc and R is the resistance of the external rheostat in kilohms.

e. MEASUREMENT OF DISSIPATION FACTOR OR STORAGE FACTOR ABOVE 1 KC.

Dissipation factor and storage factor balances above 1 kc can be obtained in the normal manner using the D and Q rheostats as the ranges of these rheostats are more than sufficient to overlap above 1 kc. All dissipation factor and storage factor readings on the black D-Q scale must be multiplied by the frequency in kc to obtain the correct values. All storage factor readings on the red Q scale must be divided by the frequency in kc to obtain the correct values.

33. Use of LRC Rheostat as a Calibrated Resistor

a. The LRC rheostat may be used independently of the bridge as an 11,050 ohm calibrated resistor. The LRC dial reading must be multiplied by 1,000 to obtain the correct reading in ohms.

CAUTION: Do not allow more than 23 milliamperes to flow through this rheostat. Higher currents may damage the resistors.

b. To use the LRC rheostat as a calibrated variable resistor, proceed as follows:

(1) Set:

- (a) CIRCUIT SELECTOR switch to any L or R setting.
- (b) GENERATOR switch to INTERNAL PWR. OFF.
- (c) DETECTOR switch to SHUNTED METER.

(2) Circuit diagrams (figs. 9, 11, and 12) show that the LRC rheostat is now available for use as a calibrated resistor by connecting to the LR (high) binding post and any binding post marked G. The LRC dial reading multiplied by 1,000 will give the value directly in ohms.

34. Use of Bridge Ratio Arms as Precision Resistors

a. The ratio arm resistors may be used independently of the bridge as precision resistors.

b. To use the ratio arm resistors as precision resistors, proceed as follows:

(1) Set:

- (a) CIRCUIT SELECTOR switch to L - $Q \times 100$.
- (b) GENERATOR switch to INTERNAL PWR. OFF.
- (c) DETECTOR switch to SHUNTED METER.

(2) Circuit diagram (figure 12) shows that the ratio arm resistors are now available across the C binding posts. The value in ohms is read from the R segment of the LRC DIAL MULTIPLIER and multiplied by 10 to give the value in ohms appearing across the C binding posts.

35. Use of Bridge Capacitor as Secondary Capacitance Standard

a. The 0.1 microfarad capacitor used as the bridge standard for capacitance and inductance measurements may be used independently of the bridge as a secondary capacitance standard.

b. To use the 0.1 microfarad capacitor as a capacitance standard, proceed as follows:

(1) Set:

- (a) CIRCUIT SELECTOR switch to C - $DQ \times .01$ or C - $DQ \times 0.1$.
- (b) DETECTOR switch to INTERNAL PWR. OFF.
- (c) DETECTOR switch to SHUNTED METER.
- (d) D-Q dial to zero.

(2) Circuit diagram (figure 10) shows that the 0.1 microfarad bridge capacitor is now available at the C (high) binding post and any binding post marked G. The 166 ohm D-Q rheostat is in series with the stand-

ard capacitor when the CIRCUIT SELECTOR switch is set at $C - DQ \times .01$ and the 1,670 ohm D rheostat is in series with the standard capacitor when the CIRCUIT SELECTOR switch is set at $C - DQ \times 0.1$.

These rheostats may be used to introduce known dissipation factors in the standard capacitor as outlined in paragraph 32. With the D-Q dial set at zero, the dissipation factor of the standard capacitor is approximately 0.0005. The capacitance between the C (high) binding post and any binding post marked G is $0.1000 \mu f$, $\pm 0.25\%$ at 1 kc and 25 degrees Centigrade. The temperature coefficient of the capacitor is less than $\pm 0.01\% / ^\circ C$ between $15^\circ C$ and $60^\circ C$.

CAUTION: Do not apply more than 500 volts peak voltage to the capacitor at frequencies up to 20 kc. Above 20 kc, the allowable voltage decreases and is inversely proportional to the square root of the frequency.

36. Use of Internal 1,000 Cps Hummer as External Tone Generator

a. The internal 1,000 cps hummer may be used independently of the bridge as a tone source.

b. To use the internal hummer as a 1,000 cps tone source, proceed as follows:

(1) Set:

(a) CIRCUIT SELECTOR switch to $C - DQ \times .01$ or $C - DQ \times 0.1$.

(b) LRC DIAL MULTIPLIER switch to $C - 0.1 \mu f$.

(c) GENERATOR switch to 1,000 CYCLES.

(d) DETECTOR switch to EXT. DET.

(2) The circuit diagram (figure 10) shows that the output of the 1,000 cps hummer is available at the LR (high) and C (high) binding posts. The frequency is 1,000 cps, $\pm 5\%$. The power available is approximately 40 milliwatts across 300 ohms. For lower impedance loads, set the LRC DIAL MULTIPLIER to $C - 1 \mu f$, which lowers the output impedance to 10 ohms.

37. Use of Bridge Galvanometer for Measurement of Small Currents.

a. The bridge galvanometer may be used independently of the bridge to measure small currents.

b. To use the galvanometer for current measurements, proceed as follows:

(1) Set:

(a) CIRCUIT SELECTOR to $L - Q \times 100$.

(b) GENERATOR switch to INTERNAL PWR. OFF.

(c) DETECTOR switch to SHUNTED METER.

(2) The circuit diagram (figure 12) shows that the galvanometer is now available at any binding post marked G and the L or C binding posts marked LO. With the DETECTOR switch in the SHUNTED METER position, the sensitivity of the meter is approximately 125-0-125 microamperes. With the DETECTOR switch in the DIRECT METER position, the sensitivity of the meter is approximately 7.5-0-7.5 microamperes.

CAUTION: Make sure that the current will not exceed 125 microamperes before connecting the meter to the external circuit. If the current is not known, always connect to the C (high) and any binding post marked G. Set the LRC DIAL MULTIPLIER to R - 100 k Ω . The circuit diagram (figure 12) shows that this places the one megohm ratio arm in series with the galvanometer as a protective resistor. Rotate the LRC DIAL MULTIPLIER counter-clockwise to place lower values of resistance in series with the galvanometer if the galvanometer does not deflect off scale.

CHAPTER 3

MAINTENANCE INSTRUCTIONS

Section I. LUBRICATION AND MAINTENANCE

38. Lubrication Instructions.

a. GENERAL. Remove the bridge chassis from the case every 6 months for cleaning and lubrication. Shorten the 6-month interval, as necessary, to compensate for abnormal conditions or activities.

b. REMOVAL OF CHASSIS FROM CASE.

(1) Unclip and remove battery cartridge from compartment at top of bridge.

(2) Prepare a soft, clean place to set the instrument. Be sure that no projections or pointed objects will be underneath the bridge panel. See that there are no metal filings around or above the exposed wiring and parts of the bridge. Filings accidentally may fall into the chassis as a result of vibration or an inadvertent arm movement, and cause electrical short circuits.

(3) Unscrew the four panel screws, lift out the chassis, and place it carefully, panel down, on the prepared surface.

CAUTION: Do not disassemble the bridge for lubrication.

c. LUBRICATION. After the instrument has been inspected thoroughly, tightened, and cleaned, lubricate as follows:

(1) Apply a thin coating of petrolatum on the contact surfaces of switches S-4 through S-6.

(2) Apply 2 drops of light oil to each of the switch bearings and detent mechanisms.

(3) Apply a thin coating of petrolatum to the cam actuated switches S-3 and S-7.

(4) Do not lubricate slide wire contacts. Precious metal contacts make lubrication unnecessary.

(5) Remove excess oil with a clean, dry cloth, and remove all traces of lint with a soft brush.

d. REPLACEMENT OF CHASSIS IN CASE.

(1) Be sure that the interior of the cabinet is thoroughly clean.

(2) Position bridge in the cabinet.

(3) Replace panel mounting screws and tighten them in place.

(4) Replace battery cartridge in compartment at top of bridge.

39. Preventive Maintenance Checklist

Item No.	What to check	When to check	How to check	Precautions
1	Panel, dials, knobs.	Weekly	Clean with soft brush.	
2	Binding posts and insulators.	Weekly	Clean off wax and dirt with soft cloth.	
3	Case and clamps.	Weekly	Rub down case with slightly oily cloth. Check, straighten and oil clamps.	
4	Oxide formed on switch contacts.	Weekly	Rotate each switch several times to assure good contact.	Bridge power must be turned off.
5	Battery and terminals.	Weekly	Clean corrosion and dirt on terminals with slightly oily cloth. Discard faulty cells. Check battery voltage.	
6	Wiring and solder joints.	Semiannually	Look for loose wires, frayed and faulty insulation, loose and poor (resin) solder joints.	
7	Resistors	Semiannually	Look for discoloration due to overheat.	
8	Microswitches (two).	Semiannually	Check for proper cam engagement, positive snap action, and continuity.	
9	Nuts on ends of basic assemblies.	Semiannually	Moderately tight, secure with cement.	Do not get cement on contacts.
10	Set screws on switch shafts and sliders.	Semiannually	Moderately tight.	
11	Sliders and slide wires.	Semiannually	Good contact pressure 1.5-2 oz. Look for corrosion and excessive wear.	Do not damage rheostat wires. Do not lubricate.
12	Switch brush and contacts.	Semiannually	Look for corrosion, bad contact and excessive wear	Do not bend brushes, loosen set screw and adjust.
13	Clean and lubricate.	Semiannually	All prescribed parts cleaned and lubricated.	Look for fungus growths and mildew in tropical locations.

CHAPTER 4

THEORY OF BRIDGE OPERATION

Section I. GENERAL

40. General Theory of Operation

A bridge is an arrangement of impedances for the measurement of various electrical properties. The basic form (fig. 9) consists of four resistance arms: A, B, U, and N. The ratio of the A and B resistances is adjustable so that the variable resistor N serves as a standard in measuring a wide range of resistor values. All four resistances are connected in series-parallel to a battery between the junctions of the A and B, and the U and N arms. When the voltage drop across arm U equals the drop across arm N, and the voltage drop across arm A equals the drop across arm B, no current flows through the galvanometer, and the bridge is considered to be balanced. This condition of balance may be expressed by the formula:

$$\frac{U}{A} = \frac{N}{B}$$

By substituting capacitors, inductors, or capacitor-resistor combinations in series or in parallel for the bridge resistors, the bridge may be used to measure a-c resistance, capacitance, inductance, dissipation factor (D), and storage factor (Q) (figs 9 through 12). Selection of the various bridge combinations is made by turning the CIRCUIT SELECTOR switch. The ratio arms of the bridge are controlled by the LRC DIAL MULTIPLIER switch. A balance is obtained by adjustment of the Q, D-Q dial and the LRC dial.

41. Description of the Bridge Circuits Used

a. RESISTANCE BRIDGE CIRCUIT. The Wheatstone resistance bridge circuit is used to make d-c and a-c resistance measurements. The circuit is arranged as shown in figure 9. This circuit arrangement is obtained by setting the CIRCUIT SELECTOR switch to Rx1 or Rx10 in the R section of the dial. The basic equation of balance for the Wheatstone resistance bridge is

$$R_u = \frac{R_n R_a}{R_b}$$

where R_a , R_b , and R_n are calibrated to make the bridge direct reading

$$R_u = R_{\text{read}}$$

When the bridge is used to make a-c resistance measurements, errors are introduced by the small residual capacitances and inductances

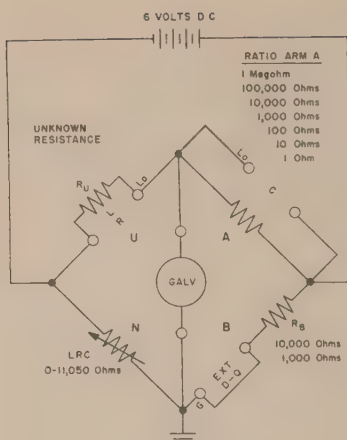


Figure 9.

Resistance bridge circuit.

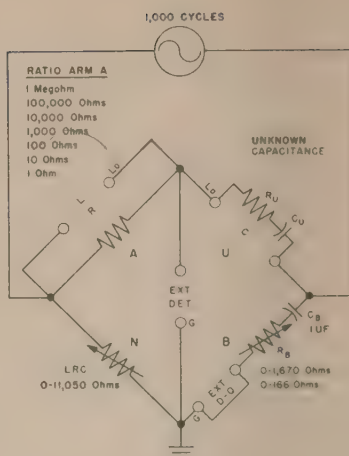


Figure 10.

Capacitance bridge circuit.

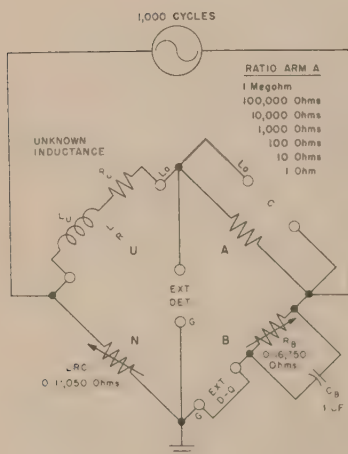


Figure 11.

Maxwell inductance bridge

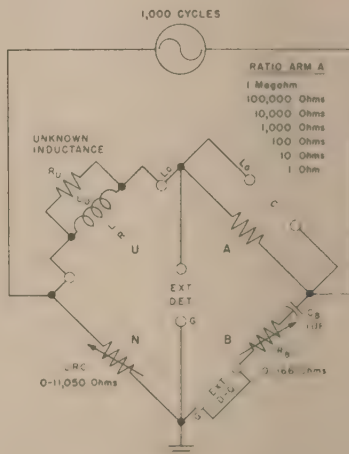


Figure 12.

Hay inductance bridge

associated with the bridge arms. Generally, the residual inductance effects are negligible, but the residual capacitance effects may introduce errors in high impedance measurements. Figure 13 shows the Wheatstone resistance bridge with residual capacitances associated with the bridge arms. The complete balance equation for this a-c resistance bridge is

$$R_u = \frac{R_a R_n}{R_b} \left[\frac{1 + Q_b (Q_n + Q_a) - Q_a Q_n}{(1 + Q_a^2) (1 + Q_n^2)} \right]$$

where the terms within the bracket represent a correction factor to be applied to the reading to obtain the true value of R_u . This type of measurement will have an associated Q . The storage factor balance equation is

$$Q_u = \frac{Q_b (1 - Q_a Q_n) - Q_a - Q_n}{1 + Q_b (Q_n + Q_a) - Q_a Q_n}.$$

where $Q_a = R_a \omega C_a$ and $Q_n = R_n \omega C_n$. The value of R_a may be determined from the LRC DIAL MULTIPLIER setting (par. 21). The value of R_n is the reading of the LRC dial multiplied by 1,000 ohms. The value of C_a is approximately $10 \mu\text{mf}$. The value of C_n is approximately $30 \mu\text{mf}$ when the internal generator is used. $Q_b = R_b \omega C_b$. Q_b may be determined as outlined in paragraph 24.

b. CAPACITANCE BRIDGE CIRCUIT. The capacitance bridge is used for measuring the capacitance and dissipation factor of capacitors and electrical components. The circuit is arranged as shown in figure 10. This circuit arrangement is obtained by setting the CIRCUIT SELECTOR switch to $DQ \times 0.1$ or $DQ \times 0.01$ in the C section of the dial. The basic equation of balance for the capacitance bridge is

$$C_u = C_b \frac{R_n}{R_a}$$

and

$$D_u = D_b,$$

where R_n , R_a , C_b and D_b are calibrated to make the bridge direct reading.

$$C_u = C_{\text{read}}$$

$$D_u = D_{\text{read}}$$

However, errors are introduced by the small residual inductances and capacitances associated with the bridge arms. Generally, the residual inductance effects are negligible, but the residual capacitance effects may introduce error when the capacitance being measured is small. Figure 14 shows the residual capacitances associated with the bridge. The complete balance equation for this bridge is

$$C_u = C_b \left(\frac{R_n}{R_a} \right) \left[\frac{1 + Q_a^2}{1 + D_b (Q_a - Q_n) + Q_n Q_a} \right]$$

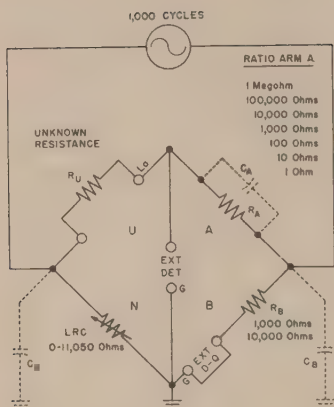


Figure 13.
Resistance bridge circuit
with major residuals.

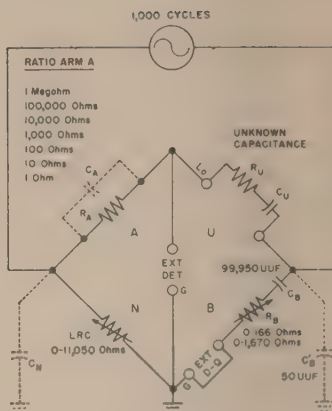


Figure 14.
Capacitance bridge circuit
with major residuals.

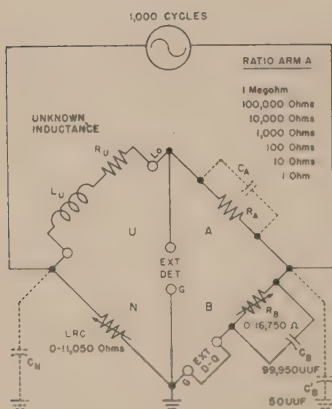


Figure 15.
Maxwell inductance bridge
with major residuals.

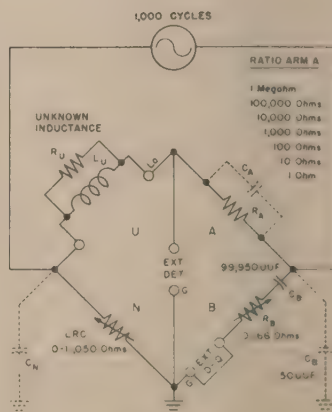


Figure 16.
Hay inductance bridge
with major residuals.

where the terms within the bracket represent a correction factor to be applied to the readings to obtain the true value of C_u .

The dissipation factor balance equation is

$$D_u = \frac{D_b + Q_n - Q_a (1 - Q_n Q_b)}{1 + D_b (Q_a - Q_n) + Q_n Q_a}$$

In both equations $Q_n = R_n \omega C_n$, $Q_a = R_a \omega C_a$, $D_b = D_{\text{read on dial}}$ where C_a is approximately $10 \mu\mu\text{f}$ and C_n is approximately $30 \mu\mu\text{f}$.

The dissipation factor error will not become large until R_a becomes large on the high impedance ranges. The correction factor to be applied to the dissipation factor readings on the $0.001 \mu\text{f}$ range can be determined by measuring the dissipation factor of a $0.01 \mu\text{f}$ capacitor on the $0.01 \mu\text{f}$ range where the error is small and then measuring the dissipation factor of the same capacitor on the $0.001 \mu\text{f}$ range. In a similar manner, the $0.001 \mu\text{f}$ range and the $0.0001 \mu\text{f}$ range may be compared using a $0.001 \mu\text{f}$ capacitor.

Note. C_b has been calibrated at $50 \mu\mu\text{f}$ below the nominal value of $0.1 \mu\text{f}$ to compensate for the bridge residual (wiring) capacitance C_b' . Therefore the effective value of C_b is $0.1 \mu\text{f}$, (figs. 10 and 14).

$$C_{B \text{ true}} = C_b + C_b'$$

c. INDUCTANCE BRIDGE CIRCUITS.

(1) *Maxwell inductance bridge.* The Maxwell inductance bridge is used for measuring inductances with storage factors below 10. The circuit is arranged as shown in figure 11. This circuit arrangement is obtained by setting the CIRCUIT SELECTOR switch to DQx1 in the L section of the dial. The basic equation of balance for the Maxwell inductance bridge is

$$L_u = R_a R_n C_b$$

and

$$Q_u = Q_b$$

Where R_a , R_n , C_b , and Q_b are calibrated to make the bridge direct reading.

$$L_u = R_a R_n C_b = L_{\text{read}}$$

$$Q_u = Q_b = Q_{\text{read}}$$

However, errors are introduced by the small residual inductances and capacitances associated with the bridge arms. Generally, the residual inductance effects are negligible, but the residual capacitance effects may introduce errors when the inductance being measured is above 10 henrys. Figure 15 shows the Maxwell inductance bridge with the residual capacitances associated with the bridge arms. The complete bal-

ance equation for series inductance measured by this bridge is

$$L_u = R_a R_n C_b \left[\frac{1 - Q_a/Q_b - Q_n/Q_b - Q_a Q_n}{(1 + Q_a^2)(1 + Q_n^2)} \right]$$

where the terms within the bracket represent the correction factor to be applied to the reading to obtain the true value of L_u .

The storage factor balance equation is

$$Q_u = \frac{Q_b (1 - Q_a Q_n) - Q_a - Q_n}{1 + Q_b (Q_a + Q_n) - Q_a Q_n}$$

In both equations $Q_a = R_a \omega C_a$, $Q_n = R_n \omega C_n$, $Q_b = Q_{\text{read on dial}}$,

where C_a is approximately 10 μmf and C_n is approximately 30 μmf .

(2) *Hay inductance bridge.* The Hay inductance bridge is used for measuring inductances with storage factors between 10 and 1,000. The circuit arrangement is obtained by setting the CIRCUIT SELECTOR switch to $Q \times 100$ in the L section of the dial. The basic equation of balance for the Hay inductance bridge is

$$L_u = R_a R_n C_b$$

and

$$Q_u = Q_b,$$

where R_a , R_n , C_b and Q_b are calibrated to make the bridge direct reading.

$$L_u = R_a R_n C_b = L_{\text{read}}$$

and

$$Q_u = Q_b = Q_{\text{read}}.$$

However, errors are introduced by the small residual inductances and capacitances associated with the bridge arms. Generally, the residual inductances are negligible, but the residual capacitance effects may introduce errors when the inductor being measured is above 10 henrys. Figure 16 shows the Hay inductance bridge with the residual capacitances associated with the bridge arms. The complete balance equation for parallel inductance measured by this bridge is

$$L_u = R_a R_n C_b \left(\frac{1 - Q_a Q_b - Q_n Q_b - Q_a Q_n}{(1 + Q_a^2)(1 + Q_n^2)} \right),$$

where the terms bracketed in order of their importance represent correction factors to be applied to the reading to obtain the true value of L_u .

The storage factor balance equation is

$$Q_u = \frac{Q_b (1 - Q_a Q_n) - Q_a - Q_n}{1 + Q_b (Q_a + Q_n) - Q_a Q_n}.$$

In both equations $Q_a = R_a \omega C_a$, $Q_b = Q_{\text{read on dial}}$, $Q_n = R_n \omega C_n$, where C_n is approximately 10 μmf and C_n is approximately 30 μmf .

The equation relating parallel inductance (L_p) and series inductance (L_s) is:

$$L_p = \left(\frac{1 + Q^2}{Q^2} \right) L_s$$

All of the above bridge circuits are treated in detail in "Alternating-Current Bridge Methods", by B. Hague published by Pitman Publishing Corporation, New York, N. Y.

42. Discussion of Residual Impedances

a. GENERAL. The causes of residual inductance, capacitance, and resistance must be considered in any bridge circuit because no impedance element, however carefully constructed, is free from residual impedances. Inductors have associated resistance and shunt capacitance, resistors have series inductance and shunt capacitance, and even air capacitors have series resistive and inductive residual impedances. Figures 13, 14, 15, and 16 show the most significant residuals in the Wheatstone resistance bridge, the capacitance bridge, and the Maxwell and Hay inductance bridges. The measured residuals and complete balance equations are given in the preceding paragraph (par. 41). From these, should the precision of measurement demand, the percentage of error due to residuals can be recognized, computed, and corrections made.

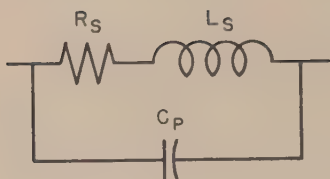
b. RESIDUAL IMPEDANCES IN RESISTORS. Every resistor contains residual components of capacitance and inductance. The magnitude of these components is determined by the type and construction of the resistor. Residuals can be balanced at only one frequency: at higher or lower frequencies the capacitance or inductance error predominates. Capacitance and inductance effects are undesirable, especially in precision resistors, and many methods of construction are employed to reduce residual impedances. Figure 17 c shows how residuals are usually associated with a resistor.

(1) Capacitance exists between adjacent turns of wire in a resistor. A resistor containing many turns of fine wire has considerable capacitance between adjacent turns. When direct current is applied, the residual capacitance does not affect the true ohmic value (R) of the resistor except by loss through insulation. If an alternating current is applied, however, energy flows through the parallel path offered by the capacitance between turns, and the impedance (Z_s) of the resistor is changed.

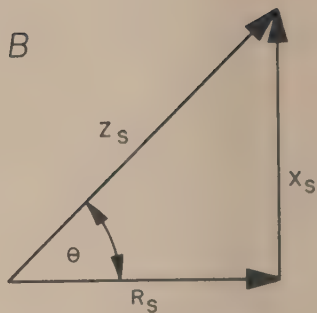
(2) Inductance (L_s) is an equally important residual found in resistors. The amount of inductance is influenced by the type and construction of the resistor.

Residual inductance is caused primarily by winding methods that do not cancel magnetic fields set up by the loops or coils of wire in

A

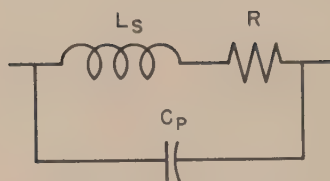


B

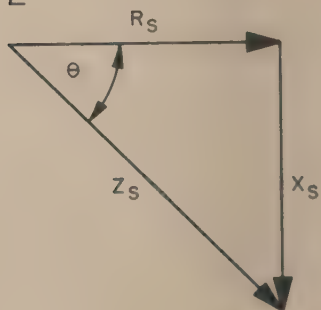


$$Q = \tan \theta = \frac{X_S}{R_S} = \frac{\omega L_S}{R_S} = \frac{1}{D}$$

C



E



$$D = \cot \theta = \frac{R_S}{X_S} = R_S \omega C_S = \frac{1}{Q}$$

D

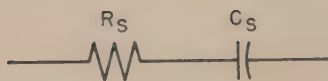


Figure 17. Residual impedances.

the resistor. The effective impedance (Z_s) of the resistor is increased with an increase in inductance or frequency.

(3) The Impedance Bridge does not contain direct methods for measuring residual impedances in an unknown resistor. Such measurements may be made as outlined in paragraph 24.

c. RESIDUAL IMPEDANCES IN CAPACITORS. Residual impedance components of inductance and resistance are associated with all capacitors.

(1) Inductance is introduced principally by the leads, frame, plate construction, and method of winding or stacking the plates. Inductance losses, which are usually low and apparent only at high frequencies, will not be discussed here.

(2) The resistance component is made up primarily of leakage or losses in the capacitor dielectric. Included in this loss is dielectric absorption, which is caused by imperfect insulation. Dielectric absorption is the inability of a capacitor to release its total charge when subjected to cyclic charge and discharge, as in an a-c circuit. Ohmic resistance of leads and plates also contribute some loss.

(3) All the residual impedances together contribute to the dissipation factor (D) of a capacitor. A capacitor with residual impedances may be represented as a perfect capacitor (C_s) (no losses) in series with a resistance (R_s) (fig. 17 d). D is the ratio of series resistance to series reactance (R_s/X_s) and varies with the losses. In figure 17 e, D is the cotangent of the angle δ (angular phase displacement). Sometimes capacitor losses are called pf (power factor), which is the cosine of the angle θ , and differs from D by less than 1 percent for dissipation factors less than 0.1.

(4) When the impedance bridge is set up to measure capacitance, the unknown is compared with standard capacitor C-2 in the bridge (fig. 10). Capacitor C-2 is connected in series with variable resistor R-21 or R-24 (depending on the setting of the DQ Multiplier switch). The small resistance losses in capacitor C-2 are considered when resistor R-21 or R-24 is calibrated. As the bridge is balanced, the resistance of R-21 or R-24 is increased or decreased by rotating the D-Q dial (fig. 1) until, at balance, its resistance is equal to the equivalent loss resistance of the unknown capacitor. Thus, the reading of the D-Q dial is a direct indication of resistance losses in the unknown capacitor under test. The D-Q dial is calibrated in D values from 0.001 to 1.0. The higher the D-Q dial reading, the greater the losses in the unknown capacitor.

d. RESIDUAL IMPEDANCES IN INDUCTORS. The first-order residual impedances found in an inductor are series resistance and parallel capacitance (fig. 17 a).

(1) Resistance in an air core inductor consists principally of series resistance of the wire and parallel losses in insulation of the wire or sealing compound. In an iron core inductor further losses are introduced by eddy current and hysteresis losses in the core iron. Residual capacitance is made up primarily by the capacitance between adjacent turns in the winding, and capacitance between the winding and the core.

(2) In an inductor, the effect of residual impedances may be represented as a resistor (R_s) in series with an inductor (L_s), and a capacitor (C_p) in parallel with the R_s and L_s combination (fig. 17 a).

(3) The combined residual losses determine the storage factor (Q) of the inductor; Q is the ratio of the series reactance to series resistance (X_s/R_s). In figure 17 b, Q of an inductor is shown as the tangent of the angle θ (tangent θ = side opposite/side adjacent = reactance (X_s)/ resistance (R_s)), and is a direct indication of the quality of the inductor. The higher the Q , the better the quality of the unknown inductor.

(4) When the impedance bridge is set up to measure inductance, the inductor under test is compared to standard capacitor C-2 (figs. 11 and 12). This comparison is possible in a bridge circuit because unlike reactances may be compared if their phase differences are considered and the bridge arms are arranged accordingly. Figures 11 and 12 show how this is done. Resistor R-24 (fig. 19) is connected in series, or R-25 is connected in parallel (depending on the setting of the D-Q Multiplier switch) with capacitor C-2 in the bridge circuit. When the bridge is balanced, resistor R-24 or R-25 is adjusted so that it is equivalent to the loss resistance of the unknown inductor under test.

The D-Q dial, which controls resistors R-24 and R-25, reads Q values directly, and is calibrated from 0.01 to 1,000 to cover the required ranges.

CHAPTER 5

REPAIR AND CALIBRATION INSTRUCTIONS

Section I. TROUBLE LOCATION AND REPAIR

43. Test, Calibration, and Repair Equipment

Tool or test equipment	Use
A Wheatstone bridge	For accurate resistance measurements
Multimeter	For voltage and resistance measurements.
Audio Oscillator	To check hummer frequency
Laboratory Standards	For checking accuracy of resistance, capacitance, and inductance readings.
Screw driver	To remove bridge from case.
Allen-head wrenches No's 8 and 10 hexagon	To loosen or tighten setscrews.

44. Preliminary Inspection and Testing

Unnecessary disassembly of the bridge may cause additional trouble instead of correcting existing trouble. Before attempting to trouble-shoot the bridge, proceed as follows to determine that faulty operation is not due to causes outside of the bridge.

a. Check the panel controls to insure that they are positioned according to instructions covering the specific measurement being performed (sec. II, or III, ch. 2). It has been found in many cases that

failure to obtain a bridge balance has been due to the wrong position of one or more of the panel controls.

b. Check connections between the bridge binding posts and the part under measurement. What appears to be an intermittent condition inside the instrument may be merely a poor outside connection.

c. Check the headset cord for breaks.

d. Check the battery voltage (par. 48) and connections to the battery. Failure to balance the bridge or the presence of a weak 1-kc note may be due to a weak battery or poor connections to the battery.

e. If the bridge balances at a value of *much* less than $100\mu\mu\text{f}$ when a capacitor with a known value of *slightly* less than $100\mu\mu\text{f}$ is measured, check the insulation between the C binding posts for moisture-bearing dirt. When capacitor measurements of less than $100\mu\mu\text{f}$ are made, be sure to consider zero capacitance of the bridge.

f. If the bridge cannot be balanced when measuring capacitance, check the capacitor under measurement for defects. It may be shorted or have a high resistance leakage.

g. If a resistor is being measured, be sure it is not open. An open resistor may damage the meter.

Note; The bridge operator must acquire a knowledge of abnormal outside conditions that are reflected in unsatisfactory bridge operation so that tampering with the bridge will be avoided.

45. Trouble Shooting Chart

Symptom	Probable cause of trouble	Procedure
Bridge inoperative for d-c measurements	Defective battery	Test battery for proper voltage (par. 48). If battery is defective, or if battery voltage under load is less than 6 volts, replace battery (par. 6).
	Faulty wiring; galvanometer will not come to 0	Check wiring to be sure that no short circuits exist and that exposed wiring does not touch the metal cabinet.
	Faulty switch	Check all switches for proper contacts and operation (par. 39).
	Open, shorted, or defective resistor	Test resistors R-1 through R-10 and R-22, R-23 for open and shorted circuits and rated values (pars. 49, 50, 58, 62 and 63).
	Faulty LRC decade-rheostat	Check R-11 through R-20 and R-26 for continuity and for accuracy of resistance values corresponding to settings of the LRC dial (pars. 51 and 64).
	Defective galvanometer	Check galvanometer for proper operation (par. 55).
Bridge inoperative for a-c resistance measurements.	Defective battery	Test battery for proper voltage (par. 48). If battery is defective, or if battery voltage under load is less than 6 volts, replace batteries (par. 6).
	Faulty switch	Check all switches for proper contacts and operation (par. 39).
	Open, shorted, or defective resistor	Test resistors R-4 through R-10, R-22, and R-23 for open and shorted circuits and for rated values (pars. 49, 50, 62, and 63).
	Faulty microphone hummer	(See Microphone hummer under Symptom column)
Bridge inoperative for capacitance measurements	Defective battery	Test battery for voltage (par. 48). If battery is defective, or if battery voltage under load is less than 6 volts, replace battery (par. 6).
	Faulty switch	Check all switches for proper contacts and operation (par. 39).
	Open, shorted, or defective resistor	Check resistors R-4 through R-10 and R-21, R-24 for open and shorted circuits, and for rated values (pars. 49, 60, 62, and 65).
	Faulty LRC decade-rheostat	Check R-11 through R-20 and R-26 for continuity and for accuracy of resistance values corresponding to settings of the LRC dial (pars. 51 and 64).
	Faulty capacitor C-2	Check capacitor C-2 for an open or shorted circuit, for leakage, and for proper value (pars. 53, 57 and 66).
	Faulty microphone hummer	(See Microphone hummer under Symptom column)

Trouble Shooting Chart (cont'd)

Symptom	Probable cause of trouble	Procedure
Bridge inoperative for inductance measurements.	Defective battery	Test battery for proper voltage (par. 48). If battery is defective, or if battery voltage under load is less than 6 volts, replace battery (par. 6).
	Faulty switch	Check all switches for proper contacts and operation (par. 39).
	Open, shorted, or defective resistor	Check resistors R-4 through R-10, and R-24, R-25 for open or short circuits and for rated values (pars. 49, 52, 60, 62, and 65).
	Faulty LRC decade-rheostat	Check resistor R-11 through R-20 and R-26 for continuity and for accuracy of resistance values corresponding to setting of the LRC dial (pars. 51 and 64).
	Faulty capacitor C-2	Check capacitor C-2 for an open or shorted circuit, for leakage, and for proper value (pars. 53, 57 and 66).
	Faulty microphone hummer.	(See Microphone hummer under Symptom column).
Readings inaccurate	Rheostat improperly calibrated	Recalibrate LRC decade-rheostat R-11 through R-20 and R-26. Also D and Q rheostats R-21, R-24, and R-25, (pars. 64 and 65).
Microphone hummer: No. 1,000 cycle tone in headset.	Weak battery or corroded battery terminals	Examine battery terminals and clean them if they are corroded. Test battery for proper voltage (par. 48), and replace if necessary (par. 6).
	Poor or open connection at hummer	Repair connection; resolder if necessary.
	Contacts or connections at switch S-1 or S-2 corroded or open	Clean contacts (par. 39), and check connections. Resolder connections if necessary.
	Switch S-3 contacts corroded or open. Cam worn down.	Replace switch S-3
	Hummer out of adjustment	Check hummer (pars. 54 and 59).
	Capacitor C-1 shorted or leaky	Check capacitor C-1
Weak 1,000-cycle tone in headset.	Dirty or corroded contacts on switches and microphone hummer connections	Clean switch contacts and hummer connections (par. 39).
	Switch S-3 contacts do not connect at LRC MULTIPLIER positions from 100Ω through 100 kΩ	Check cam for proper adjustment (par. 59).
	Capacitor C-1 leaky	Check capacitor C-1 (par. 59).

46. Trouble Shooting the Impedance Bridge

When the bridge functions abnormally and it has been ascertained that the difficulty is not due to outside causes (par. 44), the procedures in paragraphs 46 through 60 should be followed in conjunction with the trouble shooting chart (par. 45). The measurements described in paragraphs 46 through 55 should be made without removing the bridge chassis from the case.

CAUTION: Unqualified personnel must not tamper with the bridge. Unauthorized repairs will invalidate our warranty. If the tests outlined in the following paragraphs indicate the need for major repairs, our Service Department will be glad to furnish necessary repair information as well as any replacement parts. If the instrument is more than one year old, a reasonable charge may be expected for replacement parts or for complete reconditioning if the instrument is returned to the factory.

47. Preparatory Procedures

a. Obtain a Multimeter, and use it when making all the following tests.

b. Check the battery voltage (par. 48). Remove the battery cartridge from the bridge to prevent accidental application of voltage to the bridge while making the tests described in paragraphs 49 through 53.

48. Checking the Battery

To check the battery voltage without exposing the battery proceed as follows:

a. SET:

(1) DETECTOR switch to EXT. DET.

(2) GENERATOR switch to 6 VOLTS D.C.

b. CONNECT: Voltmeter positive (+) test lead to the C (high) binding post and the voltmeter negative (-) test lead to the L (high) binding post.

c. READ: Voltage as indicated by voltmeter. Normal voltage is 6 volts under load.

CAUTION: Do not set the DETECTOR switch to SHUNTED METER or DIRECT METER during the test as excessive current may pass through the galvanometer.

49. Checking Ratio Arm A Resistors (R-4 through R-10)

a. SET:

(1) DETECTOR switch to EXT. DET.

(2) GENERATOR switch to INTERNAL PWR. OFF.

(3) CIRCUIT SELECTOR switch to C - Dx.01.

(4) LRC MULTIPLIER to 0.1Ω .

b. CONNECT: Ohmmeter test leads to LR binding posts. (see basic bridge circuit, figure 10).

c. READ:

(1) Value of resistor R-10. With LRC MULTIPLIER set to 0.1Ω , the ohmmeter reading for resistor R-10 should be 1 ohm.

(2) Value of resistor R-9. Set LRC MULTIPLIER to 1Ω . The reading for resistor R-9 should be 10 ohms.

(3) Value of resistor R-8. Set LRC MULTIPLIER to 10Ω . The ohmmeter reading for resistor R-8 should be 100 ohms.

(4) Value of resistor R-7. Set LRC MULTIPLIER to 100Ω . The ohmmeter reading for R-7 should be 1,000 ohms.

(5) Value of resistor R-6. Set LRC MULTIPLIER to 1 k Ω . The ohmmeter reading for resistor R-6 should be 10,000 ohms.

(6) Value of resistor R-5. Set LRC MULTIPLIER to 10 k Ω . The ohmmeter reading for resistor R-5 should be 100,000 ohms.

(7) Value of resistor R-4. Set LRC MULTIPLIER to 100 k Ω . The ohmmeter reading for resistor R-4 plus resistor R-5 should be 1 megohm.

50. Checking Ratio Arm B Resistors (R-22 and R-23)

a. SET:

(1) DETECTOR switch to EXT. DET.

(2) GENERATOR switch to INTERNAL PWR. OFF.

(3) CIRCUIT SELECTOR switch to R - Rx1.

b. CONNECT: Ohmmeter test leads to C (high) binding post and any binding post marked G. (See basic bridge circuit, figure 9).

c. READ:

(1) Value of resistor R-23. With CIRCUIT SELECTOR set at R - Rx1, the ohmmeter reading for resistor R-23 should be 10,000 ohms.

(2) Value of resistor R-22. Set CIRCUIT SELECTOR to R - Rx10. The ohmmeter reading for resistor R-22 should be 1,000 ohms.

51. Checking LRC Decade-Rheostat (R-11 through R-20 and R-26)

The LRC decade-rheostat which comprises the N arm of the bridge, is used in making all bridge measurements. To check the LRC decade-rheostat, proceed as follows:

a. SET:

(1) DETECTOR switch to EXT. DET.

(2) GENERATOR switch to INTERNAL PWR. OFF.

(3) CIRCUIT SELECTOR switch to R - Rx1.

b. CONNECT: Ohmmeter test leads to LR (high) binding post and any binding post marked G. (See basic bridge circuit, figure 9).

c. READ:

(1) Value of rheostat R-26. Set outer LRC decade ring to zero. Set inner LRC dial to full scale (rotate dial clockwise to engage end stop). The ohmmeter reading for resistor R-26 should be 1,050 ohms.

(2) Value of decade resistors R-11 through R-20. Set outer LRC decade ring to 10. Set inner LRC dial to zero. The ohmmeter reading for resistor R-11 through R-20 in series should be 10,000 ohms.

52. Checking Q Rheostat (R-25)

To bring the terminals of the Q rheostat out to bridge binding posts for measurement of Q rheostat winding resistance, proceed as follows:

a. SET:

(1) DETECTOR switch to EXT. DET.

(2) GENERATOR switch to INTERNAL PWR. OFF.

(3) CIRCUIT SELECTOR switch to L - DQx1.

(4) LRC DIAL MULTIPLIER to 100 h.

(5) D-Q dial to 10.5.

b. CONNECT: Ohmmeter test leads to C (high) binding post and any binding post marked G. (See basic bridge circuit, figure 11).

c. READ: Value of rheostat R-25. The ohmmeter reading for rheostat R-25 should be 16,750 ohms.

Note. The terminals of the D and DQ rheostats cannot be brought out to the bridge binding posts because standard capacitor C-2 is in series with the D rheostat (R-21) and the DQ rheostat (R-24). Refer to paragraph 60 for testing of the D and DQ rheostats.

53. Checking Standard Capacitor C-2

Capacitor C-2 is connected in series with the DQ rheostat (R-24) when the CIRCUIT SELECTOR is set at DQx.01. This capacitor may be superficially checked for open circuits and shorts without removing the bridge chassis from the case. To check capacitor C-2, proceed as follows:

a. SET:

- (1) DETECTOR switch to EXT. DEF.
- (2) GENERATOR switch to INTERNAL PWR. OFF.
- (3) CIRCUIT SELECTOR switch to C - DQx.01.
- (4) DQ dial to 0.

b. CONNECT: One of the ohmmeter test leads to any bridge binding post marked G. Set the ohmmeter range selector to highest resistance range. Touch the free ohmmeter test lead to the C (high) binding post and watch the ohmmeter needle. If the needle kicks up and then drops back to infinity, capacitor C-2 is probably satisfactory. If the needle does not kick up, the capacitor is probably open. If the test lead is reapplied to the C (high) binding post, the needle should not move even though it kicked up during the first contact. If the CIRCUIT SELECTOR switch is turned to L - DQx1 and then back to C - DQx.01 again and the free test lead is then reapplied to the C (high) binding post, the needle should kick up and return to infinity if the capacitor is good. A leaky capacitor will cause a steady deflection on the ohmmeter scale, the degree of deflection depending on the amount of leakage.

Note. To test capacitor C-2 more positively, refer to paragraph 57.

54. External Check of Microphone Hummer

If the 1,000-cycle note is weak or not audible, proceed as follows:

- a.* Recheck the position of the GENERATOR switch. The hummer will operate only when the switch is set to 1,000 CYCLES.
- b.* Recheck the position of the DETECTOR switch. The hummer note will be heard in the headset only if the DETECTOR switch is set at EXT. DEF.
- c.* Recheck the shorting bar across the EXT. D-Q binding posts. See that this shorting bar is making good connections to the EXT. D-Q binding posts.
- d.* Rotate LRC DIAL MULTIPLIER switch over all seven positions several times to insure good switch contact and proper operation of impedance switch S-3.
- e.* Check the headset for open circuit, using the bridge to make d-c resistance measurements of the headset coils. Check the headset only if the hummer note is heard coming from within the bridge but not through the headset.
- f.* Check the battery voltage under load. (par. 48).

55. Checking Bridge Galvanometer

To check the bridge galvanometer for proper operation, proceed as follows:

a. SET:

- (1) CIRCUIT SELECTOR switch to R - Rx1.
- (2) LRC DIAL MULTIPLIER to 100 k Ω .
- (3) GENERATOR switch to INTERNAL PWR. OFF.
- (4) DETECTOR switch to SHUNTED METER.
- (5) LRC dial to 0.

b. READ: Galvanometer deflection when GENERATOR switch is set at 6 VOLTS D.C. The galvanometer should deflect approximately 1 division to the left (-). Set DETECTOR switch to DIRECT METER. The galvanometer should deflect 10 to 15 divisions to the left (-).

Note. If there is no galvanometer deflection or if it is not as great as indicated above, check the shunt resistors R-1 and R-2 (par. 58) and battery voltage (par. 48) before replacing galvanometer.

56. Checking Bridge Chassis

The measurements covered in paragraphs 48 through 55 were made externally to eliminate the possibility of damage to the bridge caused by removing the chassis from the case. If further tests are necessary to locate trouble, and if adequate facilities are available (par. 43), the bridge may be tested internally. To remove the bridge chassis from the case, see paragraph 38.

a. Referring to the basic bridge circuits (figs 9 through 12) and the schematic diagrams (figs. 19 and 20), use a Multimeter to test the various bridge circuits for continuity.

b. Continuity tests and resistor and capacitor measurements are important aids in locating trouble, but be sure to consider and investigate the physical condition of switch contacts, switch arms, soldered connections, and other items covered in paragraph 39. Trouble may be caused by excessive oxidation on the switch contacts or by dirty rheostat windings. When making continuity tests of the switches, check for short circuits, loose connections, corrosion, cold-soldered joints, etc., as possible causes of erroneous readings on the ohmmeter. Follow the instructions in the preventative maintenance checklist (par. 39) for inspection, tightening, cleaning, and lubrication.

CAUTION: After cleaning the rheostat windings, DO NOT LUBRICATE them, as the precious metal contacts on the rotor arms of the rheostats do not require any lubrication. Oil on the slidewires picks up lint and dust which makes the rheostats noisy.

c. If the procedures described in *a* and *b* above have been followed, resistors and capacitors tested in accordance with paragraphs 49 through 55, and the source of trouble has not been discovered, consult paragraphs 57 through 60 for internal trouble shooting procedures.

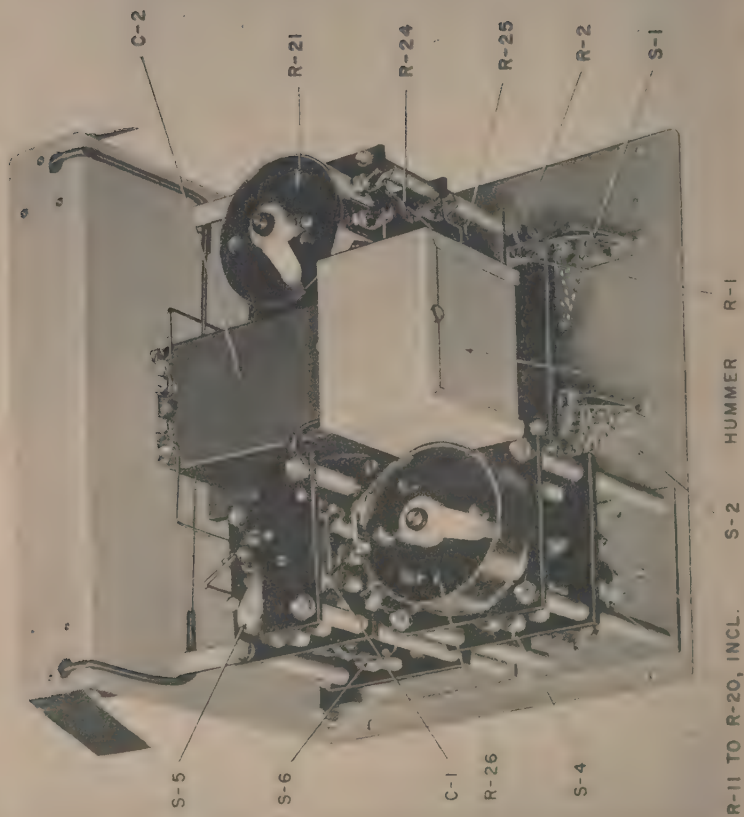


Figure 18. Bridge chassis.

57. More Positive Check of Capacitor C-2

If capacitor C-2 seems to be unsatisfactory after the test made in paragraph 53, disconnect the leads from the capacitor and check it with a capacitance bridge or capacitor analyzer.

58. Checking Meter Shunt Resistors R-1 and R-2 and Series Resistor R-3

a. RESISTORS R-1 AND R-2. (figs. 18, 19, and 20)

(1) Remove the two panel screws holding the galvanometer movement to disconnect the galvanometer.

(2) Set DETECTOR switch to EXT. DET.

(3) Using a Multimeter, check the value of resistor R-1 by placing the ohmmeter test leads across the resistor. The value of resistor R-1 should be 6,800 ohms $\pm$ 10 percent.

(4) Using a Multimeter, check the value of resistor R-2 by placing the ohmmeter test leads across the resistor. The value of resistor R-2 should be 470 ohms $\pm$ 10 percent.

b. RESISTOR R-3 (figs. 18, 19, and 20)

(1) Remove batteries.

(2) Set GENERATOR switch to INTERNAL PWR. OFF.

(3) Using a Multimeter, check the value of resistor R-3 by placing the ohmmeter test leads across the resistor. The value of resistor R-3 should be 39 ohms $\pm$ 10 percent.

59. Internal Check of Microphone Hummer

CAUTION: The tuned vibrating reed of the hummer has been factory-adjusted to oscillate at 1,000 $\pm$ 50 cycles, and should not be readjusted by unauthorized personnel. If the reed requires adjustment, replace the entire hummer and reed assembly.

a. IF 1,000-CYCLE TONE IS NOT HEARD. If the hummer is still inoperative after the checks made in par. 54, check the hummer assembly as follows after the bridge chassis has been removed from the case.

(1) Set DETECTOR switch to EXT. DET.

(2) Set GENERATOR switch to 1,000 CYCLES.

(3) Check the voltage across the battery terminals. The voltage should be 6 volts. If there is no voltage, check the soldered connections for an open circuit. Trace the yellow wire to switch S-2 and the black wire to the terminal post junction of R-3. Trace the red wire going to the hummer button. Check switch contacts on S-2 and clean if necessary (par. 39).

(4) Remove hummer shield cover and check connections to hummer terminal board.

(5) Inspect hummer reed for presence of metal filings or other foreign material in the air gap.

(6) Check the voltage from the hummer frame to the yellow primary terminal. The voltage should be 6 volts.

(7) Check switch S-3 for proper connections and operation. The switch actuating plunger should be engaged by the cam on the three lowest impedance positions of the LRC DIAL MULTIPLIER (0.1 Ω , 1 Ω , and 10 Ω) and completely disengaged on the remaining four positions. A sharp click should be heard as the cam releases the switch plunger.

(8) Check capacitor C-1 for a shorted condition by disconnecting one end of the capacitor from switch S-3 and testing it with a capacitance bridge or capacitor analyzer.

(9) Check the continuity of the hummer coils by using a Multimeter.

b. CHECKING FREQUENCY OF THE HUMMER.

(1) Connect a headset to the EXT. DET. binding posts.

(2) Set DETECTOR switch to EXT. DET.

(3) Set GENERATOR switch to 1,000 CYCLES. A tone of approximately 1,000 cycles should be heard in the headset. Obtain a signal generator capable of delivering a 1,000-cycle signal with an output of 20 volts across an impedance of 800 ohms. Connect the output terminals of this generator to another headset. With the generator controls set for low output, turn on the power switch and wait for about 30 seconds for the generator tubes to warm up.

(4) Set the signal generator for 1,000 cycles and compare the pitch of the tones from the two pairs of headsets. Usually a low frequency beat note can be heard and this may be reduced by adjusting the external generator. When the two signals zero beat, the hummer frequency may be read from the external oscillator dial.

(5) If the hummer frequency is not within 50 cycles of the nominal 1,000 cycle rating, the hummer should be replaced.

60. Checking the D and DQ Rheostats (R-21 and R-24)

Since the windings of the D and DQ rheostats cannot be brought out to bridge binding posts for measurement, proceed as follows to gain access to the rheostat terminals.

a. D RHEOSTAT (R-21).

(1) Set CIRCUIT SELECTOR switch to R-Rx1.

(2) Set D-Q dial to 10.5.

(3) Place the ohmmeter test leads across the two outside terminals of rheostat R-21. The ohmmeter should indicate 1,670 ohms $\pm$ 1%. Be sure that the rheostat slider rests against the end stop. An open in the rheostat winding may be bridged by the slider and may result in an erroneous indication on the ohmmeter.

b. DQ RHEOSTAT (R-24). Follow the procedure outlined in a above, placing the ohmmeter leads across the outside terminals of R-24. The resistance should be 166 ohms $\pm$ 1%.

61. Repairing the Impedance Bridge

Repairs are limited to adjustment of the rheostats and switches and replacement of parts. When trouble shooting indicates that a component is defective, replace that component.

Section II. CALIBRATION

62. Calibration of Ratio Arm A Resistors (R-4 through R-10)

Use a Wheatstone bridge and follow the procedure outlined in paragraph 49. If the resistors are not within tolerances given in the table below, they should be replaced.

Resistor	Value (ohms)	Tolerance (ohms)
R-10	1	$\pm$ 0.0025
R-9	10	$\pm$ 0.005
R-8	100	$\pm$ 0.05
R-7	1,000	$\pm$ 0.5
R-6	10,000	$\pm$ 5.0
R-5	100,000	$\pm$ 50.0
R-4 + R-5	1,000,000	$\pm$ 1,000.0

Note. The resistors R-9 and R-10 are intentionally made slightly less than their nominal value to compensate for the switch and wiring resistance within the bridge. The values given above are those actually appearing at the LR binding posts. Extreme care should be taken to correct exactly for the resistance of the test leads on Wheatstone bridge to insure accurate measurement of R-9 and R-10.

63. Calibration of Ratio Arm B Resistors (R-22 and R-23)

Use a Wheatstone Bridge and follow the procedure outlined in paragraph 50. If the resistors are not within the tolerances given in the

table below, they should be replaced.

Resistor	Value (ohms)	Tolerance (ohms)
R-22	1,000	± 0.5
R-23	10,000	± 5.0

64. Calibration of LRC Decade-Rheostat (R-11 through R-20, and R-26)

Use a Wheatstone bridge and follow the procedure outlined in paragraph 51. If the resistors are not within tolerance given in the table below, they should be replaced.

Resistor	Value (ohms)	Tolerance (ohms)
R-11 through R-20	1,000 (each) 10,000 (total)	± 0.5 (each) ± 5.0 (total)
R-26	1,050	± 5.0

Note. If the contact arm of the rheostat R-26 does not contact the end stops exactly at zero and at full scale, loosen the set screws holding the inner LRC dial knob on the shaft and rotate the dial into the proper position.

65. Calibration of D and Q Rheostats (R-21, R-24 and R-25)

To calibrate the D and Q rheostats, the bridge must be removed from the case. After removing the bridge from the case, proceed as follows:

- a. Set CIRCUIT SELECTOR switch to R - Rx1 and D-Q dial to 10.5.
- b. CALIBRATION OF D RHEOSTAT R-21.

- (1) Connect a Wheatstone bridge across the two outside terminals of the D rheostat R-21 (figs. 18, 19, and 20). The value of R-21 should be 1,670 ohms ± 17 ohms. If R-21 is not within this tolerance, it should be replaced.
- (2) Inspect the contact arm for proper contact with the rheostat end stops at 0 and 10.5 on the D-Q scale. If the contact arm does not contact the end stops at these dial settings, loosen the

set screws in the contact arm and rotate the arm to the proper position. Adjust the contact arm so that the moving contact bears on the rheostat winding with a pressure of approximately 2 ounces.

c. CALIBRATION OF DQ RHEOSTAT R-24

- (1) Connect a Wheatstone bridge across the two outside terminals of the DQ rheostat R-24 (figs. 18, 19 and 20). The value of R-24 should be $166\text{ ohms} \pm 1.66\text{ ohms}$. If R-24 is not within this tolerance, it should be replaced.
- (2) Inspect the contact arm for proper contact with the rheostat end stops at 0 and 10.5 on the D-Q scale. If the arm does not contact the end stops at these dial settings, loosen the set screws in the contact arm and rotate the arm to the proper position. Adjust the contact arm so that the moving contact bears on the rheostat winding with a pressure of approximately 2 ounces.

d. CALIBRATION OF Q RHEOSTAT R-25

- (1) Connect a Wheatstone bridge across the two outside terminals of the Q rheostat R-25 (figs. 18, 19, and 20). The value of R-25 should be $16,750\text{ ohms} \pm 168\text{ ohms}$. If R-25 is not within this tolerance, it should be replaced.
- (2) Inspect the contact arm for proper contact with the rheostat end stops set at 0 and 10.5 on the D-Q scale. If the arm does not contact the end stops at these dial settings, loosen the set screws in the contact arm and rotate the arm to the proper position. Adjust the contact arm so that the moving contact bears on the rheostat winding with a pressure of approximately 2 ounces.

66. Calibration of Standard Capacitor C-2

a. After the calibration of the ratio arm resistors and rheostats have been completed (pars. 62 through 65), the standard capacitor can be checked by measuring a capacitor of accurately known value with the bridge (pars. 15, 16).

b. If a high precision laboratory type capacitance bridge is available, capacitor C-2 may be disconnected from the bridge and the value of capacitance measured. The value of capacitor C-2 should be $99,950\text{ }\mu\text{mf} \pm 250\text{ }\mu\text{mf}$. If C-2 is not within this tolerance, it should be replaced.

Section III. FINAL TESTING AND REFINISHING

67. Testing the Impedance Bridge After Repair or Adjustment

After any component of the bridge has been replaced or adjusted,

and after calibration has been checked, proceed as follows:

- a.* Use a standard resistor to check accuracy of the bridge for d-c and a-c resistance measurements.
- b.* Use a standard capacitor of known dissipation factor to check the bridge for capacitance and dissipation factor measurements.
- c.* Use a standard inductor of known storage factor to check the bridge for inductance and storage factor measurements.

68. Refinishing Case of Impedance Bridge

Whenever the panel or cabinet has been scarred or damaged, touch up the outer surface to prevent corrosion of the metal. The scarred surface should be cleaned down to the bare metal with No. 00 or No. 000 sandpaper to obtain a bright, smooth finish. The bare spots should then be touched up with suitable paint.

CAUTION: Do not use steel wool instead of sandpaper. Small particles of the steel wool may enter the case and cause electrical shorting or grounding of the circuits.

INSTRUCTION MANUAL



MODEL 250-B UNIVERSAL IMPEDANCE BRIDGE

Model 250-C and Mod
Identical ins
associated with the LMC
Model

BROWN ELECTRO-MEASUREMENT CORPORATION
PORTLAND, OREGON

BECO instruments are carefully engineered and made to the most exacting standards of workmanship and accuracy in a modern and well equipped factory.

Sales representatives are maintained in principal cities as a service to our customers. Customers are invited to contact our nearest field representative or to consult our engineering staff for further information regarding BECO instruments and their applications.



WARRANTY

Brown Electro-Measurement Corporation warrants each new instrument of its manufacture to be free from defects in material and workmanship. Our obligation under this Warranty is limited to repairing or replacing any instrument or part thereof except tubes, batteries and fuses which shall, within one year after making delivery to the original purchaser, be returned to us with transportation charges prepaid and which upon our examination shall prove to have been thus defective.

Brown Electro-Measurement Corporation reserves the right to make changes in design at any time without incurring any obligation to make such changes on instruments previously sold.

This Warranty is expressly in lieu of all other obligations and liabilities on the part of Brown Electro-Measurement Corporation and Brown Electro-Measurement Corporation neither assumes nor authorizes any other person to assume any other liability in connection with the sale of BECO instruments.

BROWN ELECTRO-MEASUREMENT CORPORATION

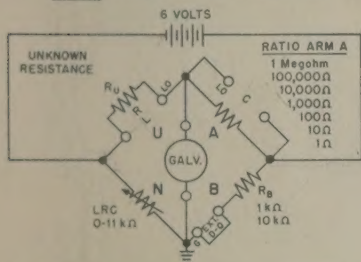
4635-37 S. E. HAWTHORNE BOULEVARD
PORTLAND 15, OREGON

Printed in U.S.A.

COPYRIGHTED 1952 BY BROWN ELECTRO-MEASUREMENT CORPORATION

Wheatstone Resistance Bridge

Range: 1 milliohm to 11 megohms



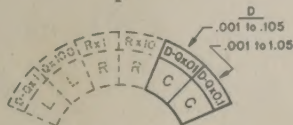
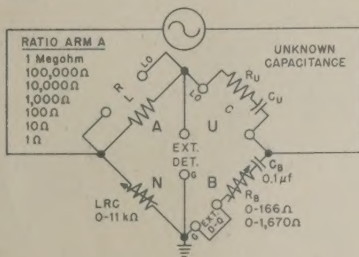
1 milliohm to 1.1 megohms



Circuit Selector Setting

Modified DeSauty Capacitance Bridge

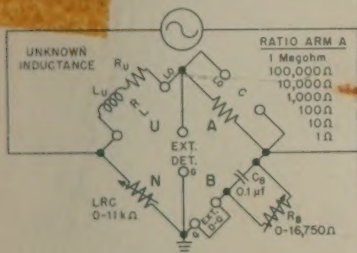
Range: 1 μ f to 1100 μ f; D_2 0.001 to 1.05



Circuit Selector Setting

Maxwell Inductance Bridge

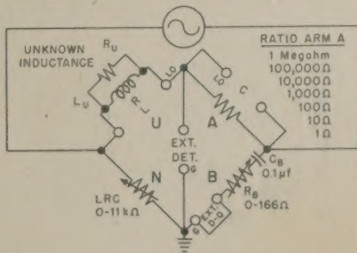
Range: 1 μ h to 1100 h; Q_2 .02 to 10.5



Circuit Selector Setting

Hay Inductance Bridge

Range: 1 μ h to 1100 h; Q_2 9.5 to 1000



Circuit Selector Setting

MP MASTER



MA35518

W.J. FORD SURPLUS ENTERPRISES

Established 1972 • 100% Employee Owned



*Wholesale • Retail
Import • Export*

*Auto
Farm • Marine • Aircraft
Equipment*

W.J. Ford & Co. Inc.
P.O. Box 283752
San Jose, CA 95128-0375

21 Market St., N. • San Jose
San Jose, CA 95133
Call 408-625-4700